Indian Agricultural
Research Institute, New Delhi.

NEW GRASSES FOR CALIFORNIA, I

PHALARIS STENOPTERA HACK.

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A survey of the soil and climatic conditions of California soon revealed the fact that most of our grasses, the seed of which is now procurable on the market, could not establish themselves and produce a strong sod on lands not susceptible of irrigation. Over large areas of the state there are good soils receiving moisture only in the form of rain on which there is no green pasturage for stock soon after the rains cease. This condition may set in as early in the season as May 1, and may continue during some seasons into November or even December. Therefore a perennial grass that will withstand the winter temperatures as well as the long, dry season in the great central valleys would be of great value to the live-stock industry of California. Recent investigations and experiments lead me to believe that I have found such a grass.

Several years ago an illustration of a grass in a trial plot in a seedsman's catalogue from South Africa attracted the author's attention. The report of its behavior under conditions of heavy frosts and long droughts made it appear that it might prove valuable under California conditions. Sufficient seed was purchased to sow one-twentieth of an acre only, as it was too costly to be considered in larger quantities. It was called perennial canary grass, or Too-woomba grass, *Phalaris bulbosa*. Perhaps the most authentic account of the introduction of this grass is to be found in the following letter received from Mr. R. R. Harding, curator of the botanic gardens, Toowoomba, Queensland.

In 1883 I received twenty-one packets of seeds from Italy. These I put in the nursery. All germinated, but the frost killed all except this wonderful grass, *Phalaris commutata*. In two years it had taken possession of nearly the whole plot of ground in the nursery from the seed self-sown.

It is a perennial. We had to remove the grass, so we dumped the root-clumps in a corner on hard ground, but it still grew to five feet in height. This was during the drouth and frost, and although it was cut it grew again.

Mr. Harding also concludes with the statement that it was distributed by him to all the Colonies, Africa, and even Italy. As will be pointed out later, neither *Phalaris bulbosa* nor *Phalaris commutata* is the correct scientific name for this grass, as those names belong to other and distinct species.

The seed secured from South Africa under the name of *Phalaris bulbosa* proved to be a strong perennial and to be pure, but not true to name. In the same year we planted a twentieth-acre plot with seed also called *Phalaris bulbosa* secured from seedsmen in Australia. It proved for the most part to be an annual *Phalaris* and not the same species as that from South Africa, although received under the same name. That there were a few seeds in this lot of the perennial species corresponding exactly to the grass from South Africa was evident, as some fifteen or twenty plants in the plot sown to the Australian seed lived throughout the next winter and summer, finally forming strong clumps.

The following year I noticed a sack of seed exhibited by the New Zealand Government at the Panama Pacific International Exposition. This, too, was labeled *Phalaris bulbosa*. The seed was so similar in appearance to the South African lot that at the close of the Exposition we arranged for its purchase. When grown, however, it proved to be an annual and not the desirable perennial grass called *Phalaris bulbosa* as received from South Africa.

A large number of packets from this sack were secured with permission from the New Zealand authorities by representatives of many experiment stations and by the United States Department of Agriculture. We desire simply to call attention to this to avoid further confusion and to make plain the fact that *Phalaris bulbosa* as distributed at the Exposition is not the same as the perennial *Phalaris bulbosa* (?) from South Africa. It is the latter grass that we desire to introduce into California, as the annual species do not offer any especial characteristics that would make them any more valuable either as pasture or hay than the cereal hays now so extensively and

satisfactorily utilized. That much, if not all, of the seed of *Phalaris* now on the markets of New Zealand and Australia is hopelessly mixed seems to be certain; and also that a selection of the perennial species will have to be made before one can recommend the purchase of seed from those countries.

A careful comparison of our perennial plant as grown at the University Farm with the original descriptions of *Phalaris bulbosa* and *Phalaris commutata* soon proved that it could be neither of those species. On further search of the literature, including descriptions of some twenty additional species, the author failed to find a description that would agree with our grass. I was about to describe it as a new species when a paper entitled *"Gramincae Novae,"* by Eduard Hackel, was discovered, in a somewhat obscure publication, which described the species in question. In order that this original description may be made more readily accessible to agronomists, we are including it here. We have been distributing seed from our plot at the University Farm and more or less confusion is likely to occur, as it has been distributed under the incorrect name of *Phalaris bulbosa.* This grass is not described or mentioned in any American literature on grasses and forage plants.

The following description with the accompanying illustrations should aid in its identification.

GRAMINEAE NOVAE IV.   Eduard Hackel *in* Fedde, *Repertorium novarum Specierum Regni Vegetabilis,* 5, 1908, p. 333.

Phalaris stenoptera Hack., nov. spec.

Perennis, caespitosa, sine stolonibus. Innovationes extravaginales, squamis elongatis herbaceis purpurascentibus fultae. *Culmi* erecti, robusti, ultra 1.5 m. alti, teretes, glaberrimi, plurinodes, simplices, internodiis basalibus non incrassatis. *Vaginae* teretes, arctae, internodiis breviores, glaberrimae. *Ligula* rotundata v. subtruncata, 5–7 mm. lg., denticulata, siccando fissa, glabra. *Laminae* lineares, sensim acuminatae, innovationum longissimae (50 cm. v. ultra), 1.2–1.5 cm. latae, culmeae superoires abbreviatae, omnes flaccidulae v. rigidulae, glaberrimae vel margine et in pagina superiore versus apicem scaberulae, virides, tenui nerves. *Panicula* spiciformis linearis vel lineari-oblonga, 6–16 cm. longa, circ. 1.5 cm. lata, densissima, haud interrupta, non vel obselete lobata, rhachi laevi, ramis appressis ramulosis multispiculatis, pedicellis quam spiculae plures v. multoties brevioribus scabris. Spiculae elliptico-lanceolatae, 5–6 mm. longa, albido-viridulae, marginibus viridi-striatae. *Glumae* steriles 2 inferiores aequales, naviculares, acutiusculae, carina in ⅔ superioribus anguste (in gluma I, angustissime vel sub-obselete) alatae, ala integra in apicem sensim decurrente, scaberula, trinerves, nervis (uno in basi alae, duobus ad latera) saturate viridibus. Gluma III nulla, IV vacua 1 mm. longa e squamula callosa ovata 0.3 mm. longa et ex appendice membranaceo lanceolato 0.7–0.8 mm. longo infra apicem squamulae inserto apice penicillato-

ciliato constans. Gluma V (fertilis) 3.5 mm. longa ovato-lanceolata, acuta, chartacea, appresse pubescens, tenuissime 5 nervis. Palae glumam aequans, angustior, carina ciliolata. Antherae 3.5 mm. longae. Ovarium glabrum. *Caryopseos* macula hilaris fere dimidiam caryopsin aequans.

Patria ignota, culta in Australia sub nomine *Phalaridis commutatae.* Plantam et semina misit A. J. Ewart, Melbourne.

Es ist auffallend, dass diese gut unterschiedene Art, welche in Australien als Futtergrass gebaut und sehr gerühmt wird, bisher meines Wissens nirgends beschrieben wurde. In Australien wurde sie durch Mr. Harding, Kurator des Botanischen Gartens in Tuwumba, Queensland (unbekannt woher) under dem Namen *Ph. commutata* eingefuhrt und unter diesem Namen von Samenhändlern in Melbourne verbreitet. Ein mir vorliegendes Reklameblatt zeigt die Darstellung eines dichten Rasens van angeblich 7 Fuss (2.2 m.) Höhe, der nach dem Schnitt in 46 Tagen wieder einen 41 Zoll (106 cm.) hohen Rasen hervorgetrieben hatte. Besonders wird sein wert als Wintergras hervorgehoben.

This excellent detailed description agrees with our grass from South Africa in everything but the sterile florets. As these are used as the chief distinguishing characters in the genus to separate one species from another, a disagreement in regard to these particular structures makes a positive identification difficult. Our specimens show a variation in the sterile florets, one 1.5 mm. in length and the other much smaller, .7 mm. The latter may be reduced to a mere point protruding from the ovate scale (pl. 1, fig. 4).

Hackel's description is as follows:

Gluma III nulla, IV vacua 1 mm. longa ... infra apicem squamulae inserto apice penicillato-ciliato constans.

That Hackel seemed convinced that there was constantly only one sterile floret is emphasized by the fact that in a discussion of the relationship of the new species, he writes "doch ist der Hüllspelzen-flügel bei *Ph. stenoptera* noch schmäler als bei *Ph. nodosa* und es ist stets nur eine kleine Leerspelze (die glume IV) am Grunde der Vorspelze"; also "Ein merkmal aber, das sie von beiden genannten Arten (*Ph. arundinacea* and *Ph. bulbosa*) scharf trennt, ist das Fehlen der gluma III, das mir ganz Konstant zu sein scheint."

Through the kindness of Mr. Harding, who forwarded us some old seed from the Botanic Gardens at Toowoomba, Queensland, we were able to examine original material. There were present in the packet some spikelets with two sterile florets, others with one sterile floret, and another very minute one and still others with only one present. This same condition was found in our specimens grown at Davis and which may be seen under sheets nos. 5000, 5001, 5002, and 5003 of

the herbarium of the Division of Agronomy, Department of Agriculture, Berkeley. Among the seeds in the packet from Harding was an outer glume whose narrow wing showed distinctly the scaberulous margin characteristic of *Ph. stenoptera.*

Hackel mentions that he received the plants and seeds from which he drew up the original description of *Ph. stenoptera* from A. J. Ewart, of Melbourne. Since the seeds of at least two species are so hopelessly mixed in Australia, is it not just possible that the seeds sent to Hackel may have been the annual species which constantly has only one sterile floret and that the plants were those of *Ph. stenoptera,* the perennial species?

A most interesting fact in connection with this grass is that it should not have been described from Europe previous to its introduction to the Toowoomba Botanical Gardens by seed sent from Italy. Hackel in his description says "Patria ignota." This from such a renowned agrostologist who has traversed the whole of southern Europe many times, is of especial significance. Could it be a hybrid from other existing species?

ECONOMIC CONSIDERATIONS

The giving of a name to this grass which will be suitable for everyday agricultural usage deserves some consideration. Perennial canary grass is not desirable, as there are several "perennial canary" grasses. Toowoomba grass is too unwieldy. I propose to call it Harding grass, after the man who first grew it in Australia.

Our experiments demonstrate that the seed may be sown at Davis during the winter season so as to take advantage of the rains. The young plants, although very slender, almost like threads coming through the ground, are very hardy and were not harmed by severe frosts. At the same time cotyledons of such hardy species as *Melilotus alba* turned yellow and many seedlings were killed outright by the drouth and cold. The grass grows rapidly, stooling profusely, and producing large clumps the first season. A feature of great merit from a pasture standpoint is the large number of dense leafy shoots produced from the base. The first year these are much in evidence and comparatively few flowering culms are sent up. These are only about two to two and a half feet tall and bear short, somewhat ovate heads. The leafage is devoid of hairy coverings of any kind, thus tending towards a clean hay and palatable pasturage.

The roots are fibrous, radiating downwards to a depth of one or two feet. They are covered with a downy coating similar to that found on many desert grasses. That they are able to make use of slight amounts of hygroscopic moisture in the soil seems possible, as when a clump was dug up and placed upon the surface of the ground the grass continued to grow, although exposed to severe conditions of drouth with no rainfall for several months.

The plot of Harding grass attracted considerable attention during the hot summer months, with its long green leaves showing no tendency to wilt. It makes a decided contrast in July and August by its vivid green among the dry brown stubble of the cereals and other grasses given the same care and treatment. We also had occasion to observe its behavior during the winter. On the coldest morning, with ice everywhere, we visited the grass plot and observed the hoar frost on the leaves and the ground frozen, yet the foliage remained green. Even our generally recognized hardy grasses like Kentucky bluegrass, orchard grass, and red top had turned brown.

The second year from the seed it still maintained a dense leafy growth from the base of about three feet, the flowering culms extending about two feet higher, making a total height of five feet. This is a growth rarely reached by any of the cultivated perennial species of grasses known at the present time.   .

We did not wish to be understood that the Harding grass will withstand a lower or as low a temperature as our common hardy grasses and that it is adapted to regions with severe winters as in parts of the east or middle west. As yet we do not know its cold-resistant qualities. The fact that it remains green during the comparatively mild winters at Davis, Yolo County, California, does not indicate the minimum temperature the roots may withstand. Information as to its latitudinal and altitudinal tolerance is not at hand.

In order that some comparison may be made as to the probable adaptability of this grass to other states and to different parts of California, we give the following conditions for Davis.

According to S. H. Beckett, of the United States Department of Agriculture, "the mean annual rainfall is 16.54 inches, the greater part of which comes in December, January, February, and March, while from May to October very little rain falls." There is considerable variation in the amount of rainfall in different years. Frequently it amounts to 20 inches, but occasionally only 8.74

inches is precipitated. It is the so-called dry years that cause a short-
age in all farm crops not under irrigation, and interfere seriously
with the pasturage on the ranges. The mean annual temperature is
62.7° F, with a known maximum of 112° F, and a minimum of 16° F.
Intense sunshine prevails throughout the summer.

Technically the soil is known as Yolo silt loam. Professor C. F.
Shaw describes it as follows:

A fine, smooth-textured brown soil at the surface, grading at about three feet
to a light brown subsoil containing slightly more clay loam or clay. It is usually
free from gravel. The soil when wet has a tendency to run together and become
puddled, preventing the free downward percolation of water. On drying it
tends to form a crust on the surface. If plowed when wet it forms hard clods
and lumps. When handled in the proper condition of moisture, however, it be-
comes loose and mellow. It has good moisture-holding capacity, is very pro-
ductive, and adapted to a wide range of crops.

That the soil has exceptionally good moisture-holding capacity,
especially at the lower depths, is shown by the following furnished
us by Professor B. A. Madson. The figures represent an average of
several plots believed to be similar in all essential details to that on
which the Harding grass was grown.

MOISTURE CONTENT OF SOIL, 1916, DAVIS

Depth, feet	Per cent Moisture, April 1	Per cent Moisture, May 25	Per cent Moisture, July 7	Per cent Moisture, August 24
1	17.35	10.34	10.32	7.44
2	21.91	12.31	12.66	11.12
3	27.39	20.75	19.47	17.00
4	27.98	19.84	20.21	16.87
5	28.60	25.44	21.19	22.01
6	34.44	27.64	28.98	27.65

The land on which the experiment with Harding grass was con-
ducted had for many years previous been cropped to grain. No
manure, artificial fertilizer or irrigation were given the plot, nor
could it have been affected by moisture from any adjacent irrigation.

A strip six by eighteen feet was cut from the plot on May 25,
1916, the second year (pl. 7). The estimated green weight of forage
per acre was twenty tons and of cured hay three tons. There still
remained on the ground a dense aftermath which would have fur-
nished good pasturage. The average yield under field conditions
can not be ascertained until the grass has been grown on a larger area.

The remainder of the twentieth-acre plot was allowed to go to
seed. From this we harvested seventeen pounds of seed, 43 per cent

of which germinated. This somewhat low viability was due to the fact that we had no fanning-mill that was suitable for cleaning grass-seed, so that much chaff remained.

From this home-grown seed we have sown an acre in rows mainly for seed increase purposes. In addition we have distributed a large number of packets to co-operative experimenters in different parts of the state in order to find out the range of soil and climate in which it might prove valuable.

In regard to its palatability, I have not yet had sufficient personal experience to determine this with certainty. Nor do we know its chemical composition or nutritive value. We fed some of the hay to work-horses accustomed to alfalfa and they ate it readily. Reports from other sources would lead us to believe that it is well liked by stock. The following excerpt from the catalogue of a branch of the well-known and reliable British seed firm, George Carter and Company, located at Pietermaritzburg, South Africa, speaks for itself.

A magnificent winter grass for fairly good lands. This is our sixth season of experience with this grass, and we have had no reason as yet to alter our high opinion of its value. For farms where the land is of a poor, light, sandy nature, we do not recommend it. But on good, fairly heavy loams (say wherever a good crop of Mealies can be grown), or on deep veldt lands, *it is magnificent.* The yield of luscious feed is tremendous all the year round, and it is particularly valuable for the winter and early spring months, growing even during heavy frost and long droughts. The rooting system is very large and deep. In seed the plants reach the height of over five feet, while the ordinary growth without seed-stems is about three feet high, and just like a permanent crop of rich green barley. It can be cut continually, growing at the rate of an inch per day. While growing with great success on dry lands, it will well repay both good manuring and irrigation.

For dairy farms we can not praise it too highly, particularly for producing milk during the colder months, when other food is so scarce; while it is just the grass to grow near the homestead for cutting for calves, horses, or indeed any animal which eats grass. There is no need to say that the cattle relish it— it is a difficult matter to keep them fenced out at all from a crop of this grass.

I refrain from quoting the praiseworthy accounts of it in the public press of Australia, as we are unable to determine whether the comments are attributed to *Phalaris commutata* or *Phalaris stenoptera,* both of which (as previously explained) are indiscriminately mixed on the seed market of that country.

Even if the Harding grass should not prove to be adaptable to a wide range of territory in California and elsewhere, the immense stretches of land between the foothills on the east and west in the great central valley, where in many instances only a poor crop of

grain is secured every other year, would be sufficient to warrant its thorough investigation.

A system of pasturing cattle and sheep on Harding grass for a period of years would be most profitable as well as beneficial to the soil.

Much, however, remains to be investigated, particularly as to its ability to withstand grazing without injury, its carrying capacity, nutritive value, longevity, and the quality of beef and mutton that it will produce.

Transmitted March 30, 1917.

PLATE 1

Phalaris stenoptera, Hack.

Fig. 1. Root system. *A.* Velvety covering on roots. *B.* Short stolons.

Fig. 2. Portion of sheath, blade, and culm. *A.* Ligule.

Fig. 3. Spikelet *A.* First empty glume. *A'* Wing of glume. *B.* Second empty glume. *B'.* Wing of glume. *C.* The lemma. *D.* Palea, *E.* Stamens.

Fig. 4. Lemma and sterile florets. *C.* Lemma. *F.* Ovate scales. *H.* First sterile floret. *G.* Second sterile floret.
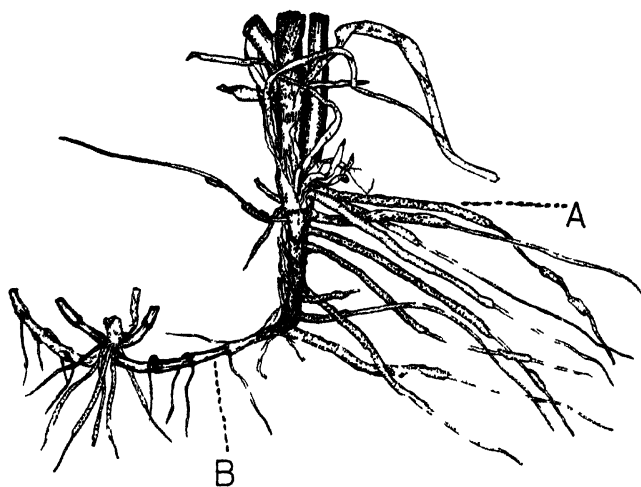
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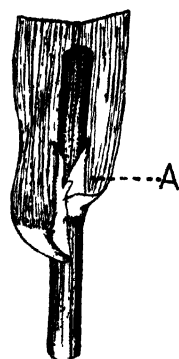
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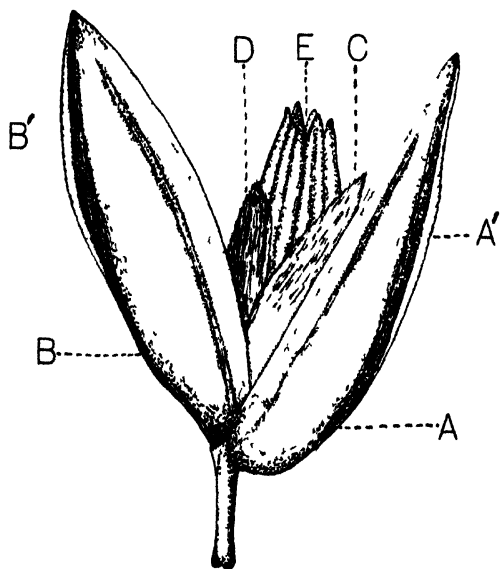
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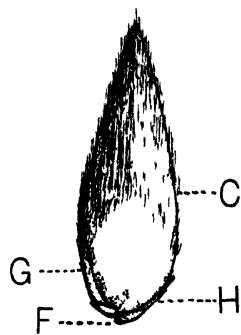
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PLATE 2

Spike-like panicles of *Phalaris stenoptera*, showing different stages of development.

PLATE 3

Young plant of *Phalaris stenoptera*, showing stooling habit and character of roots.

PLATE 4

First-year growth of *Phalaris stenoptera,* dense tender leafage in January, 1916.

Phalaris stenoptera in full bloom, second year from seed. Photo taken at University Farm, May 25, 1916. Height of plant, five feet.

PLATE 6

Phalaris stenoptera, showing strip cut across plat and dense aftermath. Photo taken May 25, 1916.

PLATE 7

Phalaris stenoptera—sheaves from experimental plot, University Farm, May 25, 1916.

PLATE 8

Lodged plants represent the annual species, the so-called *Phalaris commutata* with an erect perennial clump of *Phalaris stenoptera*. Seed came to us from Australia under name of *Phalaris bulbosa*.

OPTIMUM MOISTURE CONDITIONS FOR YOUNG LEMON TREES ON A LOAM SOIL

BY

L. W. FOWLER AND C. B LIPMAN

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Among the numerous problems emanating from the use of irrigation water on land is the important one of maintaining as nearly as possible an optimum moisture content in the soil. While much research work has been done in an attempt to determine what constitutes such an optimum moisture content, it seems that our knowledge is still too indefinite for accurate application to specific cases. For that reason it has appeared to the junior author that some specific information should be gathered concerning the moisture needs of soils which are used for growing crops under field conditions and also the variations in such moisture needs occurring through changes in soil type and changes in the kind of crop grown. Obviously the task just mentioned is too great to be disposed of quickly, and in one series of experiments, and it has, therefore, seemed wise to start the work with one crop and one soil type first. Owing to the fact that the Limoneira Company of Santa Paula, California, expressed its willingness to co-operate in such an experiment and to give to it the time and attention of the senior author as well as the necessary equipment, the experiment was started with young lemon trees on a loam soil, characteristic of much of the large ranch in the possession of the company. It was further hoped that the results obtained from the experiment, along with contemporaneous results of careful moisture determinations at short intervals in the lemon orchards, would give a basis for planning a scientific system of irrigation in the orchards in question. A plan for the specific experiment, and one for the field work were arranged by the junior author and they were executed under the direction of the senior author. The detailed results of the

field work cannot be given in this paper but will need discussion separately elsewhere at some future time. The experiment proper, however, has now been in operation for more than two years and the results obtained have been so interesting as to more than justify their presentation and discussion here.

PLAN OF THE EXPERIMENT

It was decided to grow the young lemon trees in galvanized iron cylinders, 24 inches in depth and 15 inches in diameter. The cylinders were painted with a heavy coating of asphalt. The soil used in them is a loam having the following mechanical analysis (Bureau of Soils method), which was furnished us through the courtesy of Professor C. F. Shaw:

	First foot	Second foot	Third foot
Fine gravel	1.45	1.14	1.71
Coarse sand	3.24	3.13	4.27
Medium sand	3.32	3.25	4.13
Fine sand	12.77	12.33	12.58
Very fine sand	42.99	44.93	43.22
Silt	18.74	19.31	16.61
Clay	17.49	15.91	17.48

On the basis of this mechanical analysis the Bureau of Soils would classify the soil as a *fine sandy loam*, but owing to its relatively high clay and silt content it should, in the junior author's opinion, be classified as a light clay loam, but certainly as no less than a loam. Mr. Chas. A. Jensen of the Bureau of Plant Industry, United States Department of Agriculture, was good enough to furnish the "moisture equivalents" and "wilting coefficients" of the first three feet in depth of the soil used, as it occurs under field conditions. Mr. Jensen's determinations follow:

	Wilting per cent	Moisture equivalent
First foot	9.3	17.0
Second foot	8.7	15.9
Third foot	8.1	14.0

The oil used in the cylinders was obtained from a lemon orchard now twenty-three years of age in which the trees have always shown good vigor and high productivity. The soil from the first and second feet in depth was thoroughly mixed in preparation for use in the cylinders. The same amount of soil was weighed into every cylinder.

The variety of lemons selected for the test was the Lisbon. The trees were one year old and as nearly uniform as could be obtained.

Before planting, the roots of the trees were entirely freed from soil and the tops were pruned to a whip. The planting was done on March 17, 1915, after which the cylinders were placed in a row (see plate 9) in a trench 24 inches deep, in order to prevent the undue heating of the soil from the exposure of the cylinders to the direct sun. From the time of planting until June 1, 1915, a soil moisture content of 20 per cent based on the dry weight of the soil was maintained in all the cylinders in order to give all the trees the same start. At the last date mentioned the growth of all the trees was sufficiently good and uniform enough to allow of the arrangement for the variation in moisture content in the different cylinders. In order to allow for individual variations among the trees, every moisture content was employed on triplicate trees and the moisture percentages tested were as follows:

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10 per cent based on the water-free soil.
12  "    "     "     "    "    "     "     "
14  "    "     "     "    "    "     "     "
16  "    "     "     "    "    "     "     "
18  "    "     "     "    "    "     "     "
20  "    "     "     "    "    "     "     "
22  "    "     "     "    "    "     "     "
24  "    "     "     "    "    "     "     "
26  "    "     "     "    "    "     "     "
28  "    "     "     "    "    "     "     "
30  "    "     "     "    "    "     "     "
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The cylinders are weighed three times per week and the losses of moisture due to evaporation are replaced by additions of the necessary amounts of the ordinary irrigation water employed on the ranch. The weighing is done on steelyards and a derrick is available for raising and lowering the cylinders as desired. The water is added in a depression in the surface soil corresponding in nature to an irrigation furrow and is applied by means of a very small stream flowing from a hole in a can used for the purpose. This method is employed to obviate puddling. During rainy weather the cylinders kept at less than 20 per cent moisture are protected by canvas roofs. Between irrigations the surface of the soil in all the cylinders is kept cultivated.

Results of the Experiment

Seventeen months after the experiment was started or when the trees were two years and five months old, measurements were made and a diagram showing their relative heights at the time is given in

figure 1. While, however, the measurements show clearly enough the effects of the different soil moisture percentages on the growth of the young lemon trees, they do not really tell the whole story, since the general vigor and abundance of foliage are naturally as much and perhaps more affected than the height by the moisture conditions in the soil. For that reason photographs taken at about the time the measurements were made are submitted herewith to show the actual condition of the trees.

By whatever criterion the results are gauged, it is at once clear that the effects of the soil moisture content on the development of the young lemon trees are most striking. For the soil and plant in question, 20 per cent of moisture based on the dry weight of the soil seems to be optimum in so far as the total growth and the height of
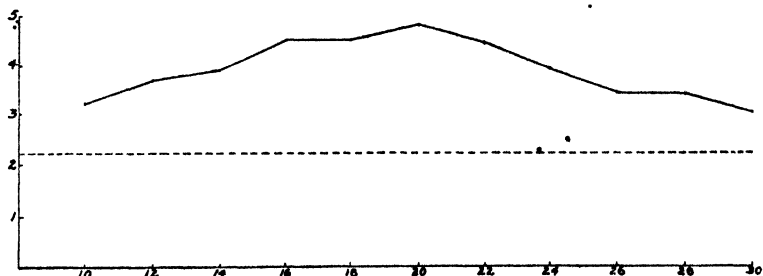
Fig. 1. Showing the relative heights of lemon trees grown with different quantities of moisture. Trees 29 months old; in experiment 17 months. The relative heights are shown on the ordinates and the percentages of moisture under which they were produced are given in the abscissae. The broken line shows the height of all the trees at the beginning of the experiment.

the trees are concerned. A fact which is not brought out by either the measurements or the photographs is that the general tone and color of the trees growing in the 20 per cent cylinders is somewhat inferior to that of the trees growing in the 16 per cent and 18 per cent cylinders. The optimum moisture content of the loam studied for young Lisbon lemons seems to be therefore between 18 and 20 per cent, if we may judge from the experiment described and from the time given it. The trees at or near the optimum moisture content doubled in height and general size during the period mentioned, while the trees at 10 per cent or at 30 per cent moisture contents have scarcely gained more than half of their original height in the period named.

Other important points deserve mention in connection with the results obtained. It appears from the data given that the range of

soil moisture percentages within which the young Lisbon trees will grow satisfactorily in the soil studied is, relatively speaking, a wide one, since for practical purposes there is probably little difference between the growth obtained at moisture percentages varying from 16 to 22, both inclusive. This is a fortunate circumstance from the point of view of orchard practice since it allows of considerable leeway in the control of irrigation operations. It does not follow, however, that as regards fruit production the same wide range of moisture percentages in the soil would be similarly effective as in the case of general vegetative growth. On either side of the range of moisture percentages just discussed, there can be no question that conditions are far from proper for good tree growth. This is especially true, however, for moisture percentages in excess of 22 per cent, at which the light-colored foliage and general lack of vigor, increasing with increase of moisture, accompany the slow growth. In the case of the cylinders receiving less than 16 per cent of moisture while the growth is also slow owing to lack of moisture, the leaves and branches appear to be normal in color and the trees appear to be suffering less from untoward conditions. It seems to be very clear at this stage of the experiment, therefore, that, in practice, there is very much more danger to young lemon trees from too much than from too little moisture in the soil. The harmful effects of the former seem to be always more sharply defined and more intense; small additions of water beyond the optimum produce large and sudden changes, whereas small decreases of moisture below the optimum show their effects only gradually with the continued reduction in the moisture percentage.

About six months have passed since the measurements and photographs discussed above were obtained. The effects of the different moisture percentages continue to stand out as clearly or more so than ever before, indicating the probability that they may continue so for a long period of years. It should be mentioned here that small but uniform applications of sulphate of ammonia have been made to all the cylinders during the past year to maintain a more nearly normal growth than is possible without additional nitrogen in such a limited volume of soil as that at the disposal of the trees in the cylinders.

In the soil under study in this experiment it was found that the theoretical wilting point was very close to, if not identical with, the actual wilting point, as both the field moisture determinations and the 10 per cent moisture cylinders have on very dry days attested. It will be observed, moreover, that the moisture equivalent and the

optimum moisture percentage in the same soil are not far apart. While the height of the trees is greatest at moisture percentages in excess of that of the moisture equivalent, the most vigorous appearance of the trees is obtained with percentages of soil moisture very close to the moisture equivalent.   As above stated, it is not possible now to discuss the detailed results of the moisture determinations in the orchard, but in general it was true that the soil moisture percentages rarely fell to the wilting point in the orchard soil and very infrequently rose to the optimum under the system of irrigation practiced. In the orchard under consideration, therefore, a lack rather than an oversupply (a common condition elsewhere in California) of water seems to be the rule.

Summary

In attempting to determine the optimum moisture content of a rather heavy loam soil for young Lisbon lemon trees grown in cylinders, at the Limoneira Ranch, Santa Paula, California, the following information was obtained in the course of the first two years of the experiment:

1. A moisture percentage of 20 per cent based on the dry weight of the soil has produced the tallest trees.

2. Trees grown with 16 and 18 per cent of moisture, while not as tall as those grown with 20 per cent of soil moisture, show better color and more vigor.   The differences are not very marked, however.

3. The foregoing facts seem to show that the range of optimum or nearly optimum moisture percentages for the soil and plant in question is a relatively wide one.

4. Much more visible damage results to the young lemon trees from moisture percentages in excess of the optimum than from those below the optimum.

5. Every successive increment of moisture beyond the optimum is accompanied by a sharp depression in growth, color, and general vigor of the trees.

6. Every successive decrement of moisture from the optimum shows only a relatively slight depression in growth.

7. The theoretical wilting point and the moisture equivalent for the soil studied are in close accord respectively with the actual wilting point as determined in the soil of the orchard and the optimum moisture content as determined in the experiment discussed above.

PLATE 9

Fig. 1. Showing arrangement of cylinder experiment to study water needs of young lemon trees.

Fig. 2. From right to left, cylinders 1, 2, and 3 maintained at 10 per cent of soil moisture; cylinders 4, 5, and 6 maintained at 12 per cent of soil moisture.
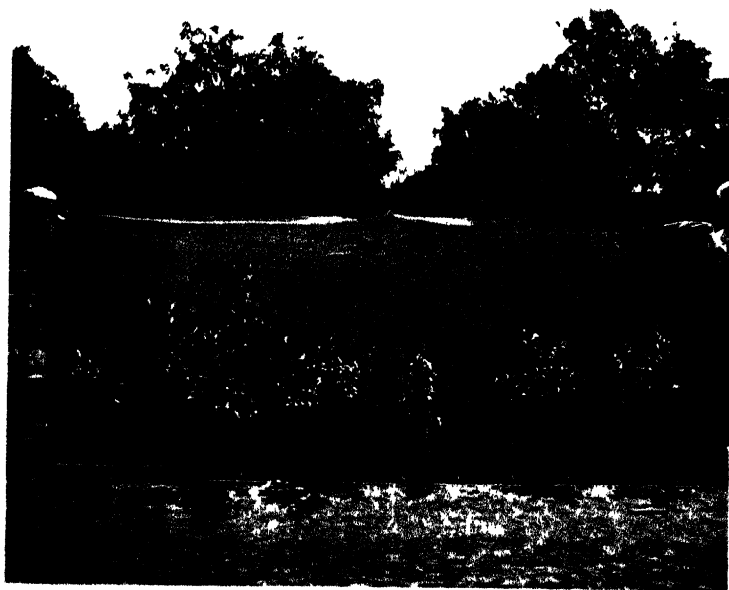
Fig 1

Fig 2

PLATE 10

Fig. 1. From right to left, cylinders 1, 2, and 3 maintained at 14 per cent of soil moisture, and cylinders 4, 5, and 6 maintained at 16 per cent of soil moisture.

Fig. 2. From right to left again, cylinders 1, 2, and 3 maintained at 18 per cent of soil moisture, and cylinders 4, 5, and 6 maintained at 20 per cent of soil moisture. Part of cylinder 7 showing 22 per cent of soil moisture.
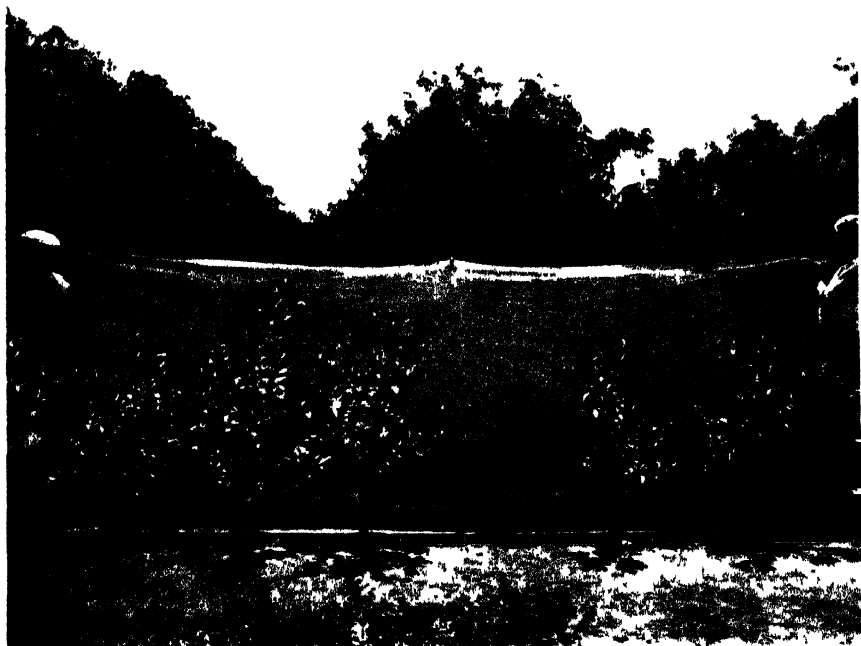
Fig 1

Fig 2

Fig. 1. From right to left, cylinders 1 and 2 maintained at 22 per cent of soil moisture, cylinders 3, 4, and 5 at 24 per cent of soil moisture, cylinders 6 and 7 at 26 per cent of soil moisture.

Fig. 2. From right to left, cylinder 1 at 26 per cent of soil moisture, cylinders 2, 3, and 4 at 28 per cent of soil moisture, cylinders 5, 6, and 7 at 30 per cent of soil moisture.

Fig 1

Fig 2

SOME ABNORMAL WATER RELATIONS IN CITRUS TREES OF THE ARID SOUTH-WEST AND THEIR POSSIBLE SIGNIFICANCE

BY

ROBERT W. HODGSON

SOME ABNORMAL WATER RELATIONS IN CITRUS TREES OF THE ARID SOUTH-WEST AND THEIR POSSIBLE SIGNIFICANCE

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INTRODUCTION

The progress of the development of the citrus industry, in general, and that of California in particular, has frequently been retarded or temporarily stopped by serious obstacles in the form of insect pests or plant diseases. Some of the most baffling of these troubles fall naturally into a group which for want of a better name has come to be known as that of "physiological diseases," which are thought to be caused by various obscure derangements of nutrition or other vital functions. This group includes mottled-leaf, die-back, chlorosis, June drop, puffing of the fruit, and others of less importance. Knowledge of the true nature of this class of diseases is extremely meager in spite of the fact that they have received much earnest attention from scientific investigators; and little can be accomplished in the way of devising control measures until much more is known in regard to them. Nor can we hope to progress far beyond the realm of speculation without greatly augmenting our knowledge of the physiology and anatomy of the normal citrus tree when grown under any one of a series of very widely varying environmental complexes which obtain in different parts of the arid southwest.

It is, therefore, proposed to attempt by means of a series of systematic experimental studies to obtain some definite and accurate information on the physiology of the genus *Citrus*. It is hoped that the results may serve as a basis for the elucidation of some, at least,

of the important problems referred to above. The studies in question will attempt to shed light on transpiration problems, nutrition problems, and others equally important. The paper which is submitted herewith forms an introductory contribution to the subject under investigation.

The writer is not unaware of the essential similarity between the physiological problems presented by citrus and other fruit trees. He has chosen, however, to study the physiology of the citrus tree as a separate entity because of the reasons given above, and the further one that the peculiar climatic conditions under which this tree is frequently placed in the arid southwest, demand a special treatment. Doubtless much may be gained from these studies which will apply to physiological problems connected with other trees.

The data here presented were obtained during an investigation of one of the so-called physiological diseases above mentioned, namely, the June drop.[1] Ever since the Washington Navel orange has been grown in the dry interior valleys of Arizona and California, this variety has been subject to excessive dropping of the young fruits. This has came to be known popularly as the June drop although the fall of the fruits is by no means confined to June but may occur at any time from petal fall, in April, until the fruit reaches several inches in diameter in August. The prevalence and amount of this dropping seems to be influenced to a marked degree by certain environmental factors to which the trees are subject. The regular annual shedding of the young fruits is most serious in regions where the annual precipitation is lowest, the mean summer temperature highest, atmospheric humidity lowest, solar radiation most intense, and air movement greatest during the growing season. That the excessive drop of young fruit is in some way intimately connected with extreme climatic conditions is indicated by the fact that in some parts of southern California, where the drop is ordinarily not excessive, the hot wave of June 15-17, 1917, during which a temperature of 118° F was experienced in the Riverside and Redlands districts, was immediately followed by a drop so severe that practically the entire young crop of navel oranges was lost.

The experimental work from which the data were obtained was carried on at Edison, Kern County, California. Edison comprises

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[1] This investigation, which is now in progress, was carried on in collaboration with Professor J. Eliot Coit who planned the first series of experiments and began the work in February, 1916. A joint authorship paper correlating this and other aspects of the June drop phenomenon is in course of preparation.

a small colony of about seven hundred acres of orange orchard located eight miles southeast of Bakersfield and surrounded on two sides by typical desert of the southern San Joaquin valley, with its characteristic semixerophytic flora. Extreme climatic conditions, as above mentioned, are operative there but the Washington Navel orange matures early and is of excellent quality, although crops are small because the drop referred to is excessive.

Water Relations and Abscission

It has long been recognized that abnormalities or irregularities in the water relations of plants are often associated with the abscission of various plant parts. Balls[2] was able to cause complete shedding of leaves, flower buds, and bolls of the cotton plant *Gossypium herbaceum* within four days by pruning the roots and so limiting the ability of the plant to take up water. Lloyd in his investigation of the cause of abscission in the same plant came to the conclusion that the causative factor lay in a steady decrease in the moisture content of the soil in contact with the roots of the plant. This reduction causes a severe tax on the power of the plant to maintain normal water relations and results in fluctuations in the water content of the aerial parts which, in turn, leads to abscission.

Although the work of Lloyd was performed in the humid southern states, he makes the statement that "there seldom occurs a day on which there is no minus water fluctuation in the plant." He based this conclusion not only on data derived from shedding records but also on a study of transpiration rates, and water deficit in the leaves. In connection with his observations on the effect of temperature in causing acceleration of abscission, he came to the conclusion that "the water deficit is the cause of the rise of temperature in the tissues and that this constitutes the stimulus which directly leads to abscission."

Other evidence of the occurrence of marked deficits in the water content of plant organs is not lacking. Livingston and Brown,[4] working with a number of plants growing near Tuscon, Arizona, found that (with the exception of the true xerophytes as *Covillea* and *Prosopis*) during the afternoon the leaves suffered a marked decrease in water content which was made up during the night. This periodic

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[2] Cairo Sci. Jour., vol. 5, p. 221, 1911.

[3] Trans. Royal Soc. Can., ser. 3, vol. 10, p. 55, 1916, see also Bull. Torr. Bot. Club, vol. 40, p. 1-26, Jan., 1913.

[4] Bot. Gaz. vol. 53, p. 319, April, 1912.

diurnal condition of dessication has been found by Livingston and Brown to serve as a check on the absolute transpiration and has been termed "incipient drying." Lloyd[5] independently obtained similar results in his investigations on *Fouquieria splendens* and Mrs. Shreve[6] established the same phenomonon in 1913 with *Parkinsonia microphylla*.

Inasmuch as the genus *Citrus* is undoubtedly a mesophyte of tropical origin and therefore grown in the interior valleys of California under purely artificial conditions,[7] it would naturally be expected that the abnormal water relations above discussed might obtain to an unusual degree, especially during the hot growing period, when the ability of the plant to make up for excessive transpiration is taxed to the limit. Citrus fruits are borne on wood of the current season's growth which ordinarily bears six to eight leaves on the same fruiting shoot. Therefore, it seemed reasonable that under conditions of excessive transpiration the leaves might draw on the water supply of the fruits and thus bring about an abnormal water relation. With the above considerations in mind it occurred to the writer that this premature fall of the fruits might be due to irregularities or abnormalities in the water relations between the fruits and foliage, resulting in abscission in some way analagous to the shedding of cotton bolls under the stimulus of a water deficit.

The method used in obtaining the data here presented consisted in the main of simple moisture determinations of leaves and fruits of various kinds taken at different hours of the day. The material was gathered and quickly placed in weighing cups fitted with ground glass covers. After weighing, the material was thoroughly dried and then reweighed. For convenience in the case of fruits and large leaves, the material was cut into small pieces. The calculations are based on the dry weight of the material, except as otherwise stated. The data obtained are shown in condensed form in table 1. The figures shown represent averages of at least ten duplicate determinations, and in most instances of more.

The data presented in table 1 show some very interesting conditions. It is quite clear that, with the exception of the new succulent growth, the young fruits are at all times higher in water content than the leaves situated near them. These data also seem to leave no doubt

[5] Plant Wor'l, vol. 15, p. 11, 1912.

[6] Ann. Rpt. Dir. Bot. Res. C. I. W., Feb. 12, 1913, p. 81.

[7] For a more complete discussion see Livingston, B. E., "A single index to represent both moisture and temperature conditions as related to plants." *Physiological Researches*, vol. I, No. 9, April, 1916.

TABLE 1

AVERAGE MOISTURE CONTENT

Kind of material	Average water content in per cent (Dry weight)
New leaves about two weeks old	242.0
Full grown leaves of current season's growth	162.2
Leaves of one season's growth—about one year old	132.7
Leaves of two season's growth—about two years old	126.1
Leaves of three or more season's growth. Over two years old	117.6
Leaves of current season's growth. Gathered between 9 A.M. and 12 P.M.	164.9
Same gathered between 1 P.M. and 4 P.M.	157.2
Leaves of current season's growth gathered from behind fruits between 9 A.M. and 12 M.	166.8
Same gathered between 1 P.M. and 4 P M.	160 4
Fruits destined to subsequent abscission, one third to three fourths inch in diameter	191.5
Fruits apparently normal gathered between 9 A M. and 12 M s	260 2
Same gathered between 1 P.M. and 4 P M.	247 7
Fruits destined to subsequent abscission gathered between 9 A M. and 12 M.	201.4
Same gathered between 1 P.M. and 4 P M.	179.2

of the fact that as the leaves grow older there is a progressive decrease in water content.

It is also quite evident that a regular diurnal decrease in the water content of leaves of the current season's growth is manifest during the afternoon. Such leaves averaged 164 9ᶜ in water content for the period between 9 A.M and 12 M. and only 157 2ᶜ for the period between 1 P.M. and 4 P.M. This difference does not appear significant when viewed in the light of the large differences obtained by Livingston and Brown with some of their material. However, it should be borne in mind that those authors were dealing, for the most part, with much more succulent plants containing a large amount of water storage tissue. Further, it should be noted that these figures are averages, since the determinations on which they are based were not made at the same hours. Individual pairs of determinations frequently showed differences of as much as 25ᶜ to 30ᶜ in as short a period as six hours. On June 5 at 2:30 P M., with the temperature at 95ᶜ F and the relative humidity at 19ᶜ, the water content of leaves of the current season's growth was 144.3ᶜ. At 4 A.M. the next morn-

ˢ The fruits used for these determinations averaged a little larger than those gathered in the forenoon and therefore would normally be somewhat higher in water content.

ing, with the temperature at 62° F. and the humidity 54%, the water content of similar leaves was found to be 172.6%, showing a difference of 28.3%. This phenomenon is taken to indicate the presence of incipient drying in citrus and is in full accord with the results of the writers above mentioned as well as with those obtained by Lloyd.

Since the young fruits have a higher water content than adjoining leaves which, in turn, exhibit a diurnal decrease in relative water content, the conclusion, *a priori*, that the leaves might possibly draw on the water supply of the fruit during periods of excessive transpiration seemed entirely plausible. If such is the case it would seem that leaves so favorably situated should not show this daily variation, at least to the degree shown in the leaves not so favorably situated. The data in table 1 show, however, that the average difference in water content of the two sorts of leaves gathered in the forenoon and afternoon is quite small. This is taken to indicate that if such leaves do utilize the water supply of the fruits, the evaporating power of the atmosphere is so strong that as fast as they receive this surplus water, it is lost and thus causes no appreciable difference in their relative water content.

The next step was to ascertain the water content of different kinds of fruits, those destined to remain and mature, and those showing indications of subsequent abscission. It is quite easy to distinguish between the two, from a week to ten days before abscission occurs, by the difference in their appearance. Exposed fruits destined to drop exhibit a small yellow spot about the navel end several weeks before the actual drop occurs. This spot gradually extends and spreads until at abscission it usually occupies at least half the area ' of the fruit. In the case of well-shaded fruits, the yellow color is evenly distributed over the entire surface. A large number of moisture determinations were made which showed that those fruits destined to subsequent abscission averaged 59% less water than those fruits destined to remain and mature. (See table 1.) The presence of this condition in the fruits, especially when considered in connection with the daily increase at certain hours in the water deficit of the leaves immediately behind them, seems to point to the possibility of the leaves depriving the fruit of a part of their normal water supply. It certainly indicates an abnormal water relation.

Lemon growers prune their trees at all seasons of the year, even while the fruit is still on the trees. It is a well established practice to gather the good fruit from the excised branches immediately, in order to prevent it from becoming flaccid. Inasmuch as the fruit, as ordi-

narily picked from the tree, remains turgid for several months, it is the common belief that the leaves draw the water out of the fruit when the branch is severed from the tree. That this is exactly what does occur, when the leaves are deprived of their normal water supply, is shown by the following experiments:

Experiment 1 — Two shoots bearing small terminal oranges of approximately the same size and having the same number of leaves and approximately the same leaf area, were taken to the laboratory, placed on the table and allowed to dry under similar conditions except that in one case the fruit was severed from the stem. All cut surfaces were sealed with vaseline.

Within twelve hours a marked difference in appearance was observed. The leaves on the shoot from which the orange was detached were considerably shriveled while those on the other shoot remained turgid and fresh. This difference became more pronounced as time elapsed and in thirty hours a distinct difference in the appearance of the fruits as well as leaves was visible. The detached fruit remained firm and retained its dark green color and lustre while the attached fruit was soft and flaccid and exhibited a dull green color without lustre. This experiment was performed repeatedly with both oranges and lemons with the same results. (See plate 12, fig. 1.)

As all the cut surfaces were sealed, it seems clear that the leaves on the shoot with fruit attached actually drew on its water content and that it was this supply of water which enabled them to remain alive and fresh long after the leaves on the other shoot had withered and died.

Experiment 2—Quantitative data on water content were desired to substantiate the visible indications described in Experiment 1. Therefore the latter was repeated several times and moisture determinations on leaves and fruits were made at various periods. A representative set of such determinations is given in table 2:

TABLE 2

MOISTURE CONTENT DETERMINATIONS, TWENTY FOUR HOURS AFTER BEGINNING OF EXPERIMENT 2

Kind of material	Weight of container and fresh material in grams	Weight of same when dry	Weight of material in grams	Water content per cent
Orange detached from branch	23.40	21.670	2.665	185 0
Orange attached to branch	23.585	22.367	2.075	142.1
Leaves from branch with fruit removed	{ 21.831 } 22.045	21.805 22.010	.181 .170	.. .. 21.4 avg.
Leaves from branch with fruit attached	{ 21.345 } 20.604	21.275 20.477	.175 .284	. 73.7 avg.

These data show that after twenty-four hours the leaves on the shoot with orange attached contained an average of 52.3% more water than those on the other shoot. They further show that the detached fruit contained 42.9% more water than the attached fruit from which the leaves had been drawing their supply. This is considered to be conclusive evidence that in the case of excised branches the leaves can draw water from the fruit.

Experiment 3—Two shoots in every respect similar to those used in the previous experiments were treated in the same manner as those of Experiment 1 and 2. These were then weighed at irregular intervals until they had reached a constant weight. During the interim they were kept on the laboratory table. The data obtained are found summarized in table 3:

TABLE 3

WATER CONTENT DETERMINATIONS MADE AT IRREGULAR INTERVALS BASED ON
THE WHOLE WEIGHT

	Shoot with orange attached				Shoot with orange detached		
Number of hours elapsed	Weight in grams	Loss in grams	Loss in per cent	Difference in per cent	Weight in grams	Loss in grams	Loss in per cent	Difference in per cent
0	4.872	. .	.	. .	4.777	....	. . . .	. . .
3	4.436	.436	8.9	.6	4.380	.397	8.3	...
19	3.957	.915	18.7	. . .	3.830	.947	19.8	1.1
21	3.895	.977	20.0	. .	3.742	1.035	21.7	1.7
24	3.803	1.069	21.9	. .	3.607	1.170	24.4	2.5
26	3.683	1.189	24.4	...	3.442	1.335	27.9	3.5
27	3.610	1.262	25.9	....	3.342	1.435	30.0	4.1
44	3.263	1.609	33.0	.	2.911	1.866	39.1	6.0
49	3.047	1.825	37.4	. .	2.682	2.095	34.8	6.4
51	2.920	1.952	40.0	. .	2.575	2.202	36.0	6.0
91	2.125	2.747	56.3	....	2.008	2.769	57.9	1.6
96	2.053	2.819	57.8	.	1.960	2.817	58.9	1.1
99	2.000	2.872	58.9	. .	1.935	2.842	59.5	.6
116	1.921	2.951	60.5	....	1.873	2.904	60.8	.3
119	1.894	2.978	61.1	..	1.852	2.925	61.2	.1
121	1.881	2.991	61.3	. ...	1.844	2.933	61.4	.1
140	1.825	3.041	62.5	.4	1.807	2.970	62.1	. .
146	1.797	3.075	63.1	.5	1.783	2.994	62.6	....
162	1.774	3.098	63.5	.6	1.770	3.007	62.9	. ..
186	1.736	3.136	64.3	.8	1.743	3.034	63.5	....
195	1.717	3.155	64.7	.9	1.726	3.051	63.8	...
211	1.705	3.167	65.0	1.1	1.720	3.057	63.9	....
218	1.695	3.177	65.2	1.0	1.710	3.067	64.2	....
260	1.666	3.206	65.8	1.1	1.686	3.091	64.7	....
285	1.652	3.220	66.0	1.1	1.675	3.102	64.9	. ..
306	1.642	3.230	66.2	1.1	1.664	3.113	65.1	....
330	1.631	3.241	66.5	1.1	1.652	3.125	65.4	....
525	1.613	3.259	66.8	1.0	1.631	3.146	65.8	....

The data in this table indicate that the amount of water in the fruit available for use by the leaves was sufficient to maintain the latter alive for approximately 50 hours after the shoot was cut from the tree. It is further evident that when three hours had passed the leaves on the shoot with fruit attached had not yet begun to take water from the fruit to any appreciable extent because the shoot with fruit detached shows less water loss than the shoot with fruit attached. However, this condition was soon reversed and the leaves began to
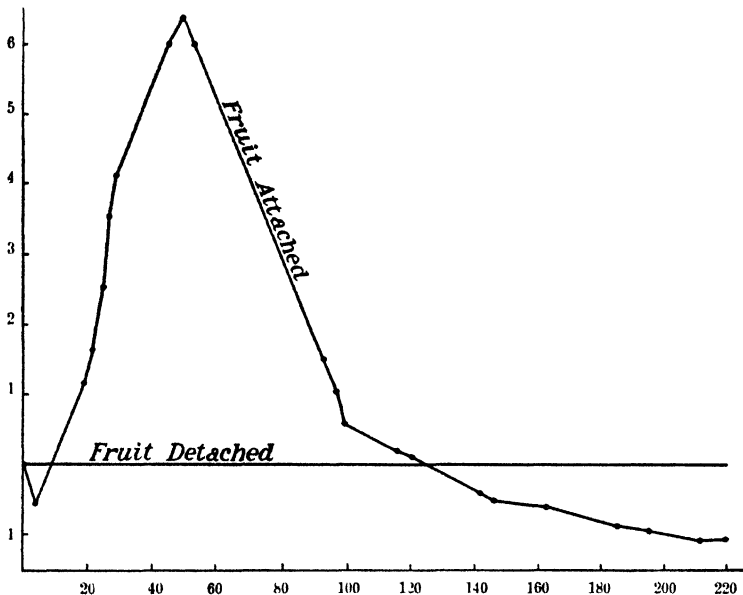
Fig. 1. Showing the difference in per cent of water loss of shoot with orange attached and shoot with orange detached. The water loss curve of the shoot with fruit detached is considered as normal. Ordinates represent differences in per cent of water loss, abscissae, the time elapsed in hours. Water content calculated on basis of fresh weight.

draw on the water in the fruit while the leaves to which no water was available from the fruit showed indications of wilting.

That shortly after 50 hours had passed death occurred in the leaves of the shoot with fruit attached is shown by the rapid increase in the amount of water loss. This was undoubtedly due to increased permeability of the cytoplasmic cell membranes after death. After 50 hours the difference in water content of the two was 18.3% in favor of the shoot with fruit attached. However, from this time on until both had reached a constant rate of water loss (after about 200

hours), this shoot lost water more rapidly than the shoot with fruit detached. These relations are very clearly shown in figure 1. The normal water loss curve is illustrated in figure 2.

Experiment 4—A forked twig bearing a small terminal fruit on each branch was selected and cut. The fruits were immediately immersed in water and the shoot tied to a support in such a fashion that all the leaves were exposed to the air, the fruits alone being immersed. One orange was now removed by cutting it under water and all cut surfaces were sealed. The two fruits remained under
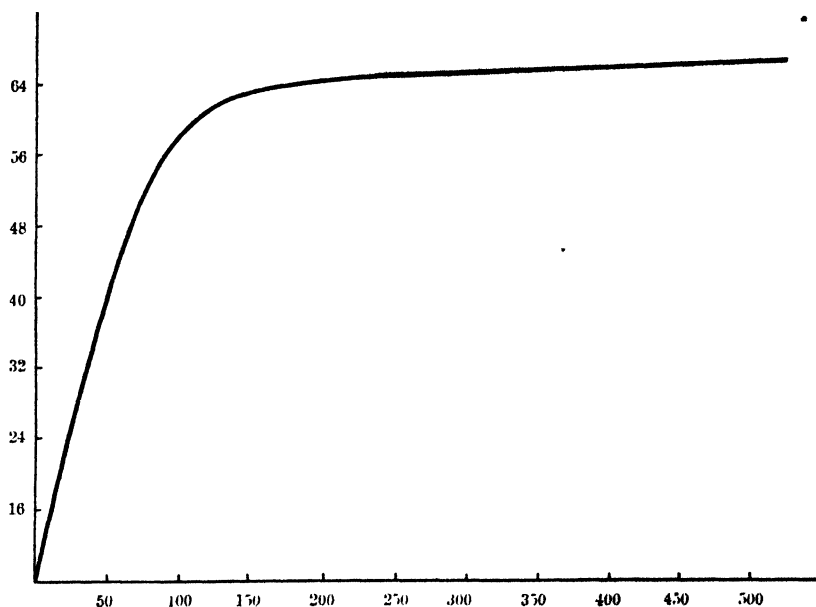
Fig. 2. Showing the general type of water loss curve of a shoot detached from the tree, including detached orange. Ordinates represent water loss in per cent and abscissae, the time elapsed in hours.

water. The container and support were then placed on a bench in the shade in the open air and left for fifteen hours, at the end of which time moisture determinations were made on the fruits.

TABLE 4

MOISTURE DETERMINATIONS AFTER FIFTEEN HOURS

Kind of material	Weight of container and fresh material in grams	Weight of same when dry in grams	Weight of material in grams	Water content per cent
Detached orange	24.680	21.435	3.330	206.9
Attached orange	23.210	21.773	2.570	126.8

The data in table 4 show that at the end of fifteen hours there was a difference in water content between the two fruits of 80.1%. There seems to be no way of accounting for this large difference other than that the leaves had actually drawn the major part of it at least, from the attached fruit.

Water Transport Studies by Means of Dye Stuff Solutions

Experiment 5—Bearing the foregoing findings in mind, it seemed desirable to determine something of the nature of this reversal of normal water flow by means of dye solutions. Accordingly a shoot bearing a terminal fruit was cut from the tree and the orange pared away at the apical end to open the tracheal elements and admit the dye.[9] This paring was done under the solution to prevent the entrance of air bubbles. Water soluble eosin was used. The orange was immersed in the liquid for a half hour, after which the shoot was split open. The tracheal tubes throughout all parts of the leaves, stems and fruits were found to be strongly stained.

Experiment 6—It seemed desirable to simulate the actual situation on the tree as nearly as possible and the following experiment was designed to accomplish this. A crooked fruiting branch bearing a number of small lateral shoots and leaves, and one terminal orange was cut under water. The cut end was kept under water and the branch so supported that the fruit was immersed in an eosin solution. The apex of the orange was then pared as described above. The branch then rested with its basal end in water and the vascular bundles of the fruit open to eosin at the other end of the branch. (See pl. 12, fig. 2.) If we substitute for the water container the conducting system of the tree, and for the watery solution of eosin the developing fruit high in water content, we have very similar conditions to those existing in the experiment, save for the fact that the fruit is not open to the air and the conducting system bears a certain relation to the rest of the tree.

The experiment was begun late in the afternoon and the branch left outdoors over night. At 8 o'clock the next morning the leaves were examined and found to be very fresh and turgid. Indeed they were noticeably much fresher in appearance than they had been the evening before. On careful examination absolutely no trace of eosin

[9] It should be stated here that the Washington Navel orange is in reality a double fruit, with a small secondary orange within a large primary fruit. This interior fruit constitutes what is known as the navel and it possesses an independent vascular system of its own which traverses the central pith of the primary fruit before ramifying through the secondary orange. This central pith thus acts as the stem to the small fruit.

could be found in any part of the shoot. Samples of leaves for mois-
ture content determination were taken at 8:30 A.M. Although remain-
ing in the shade the leaves showed at 12:15 P.M. distinct evidence of
wilting and upon examination, eosin staining was found in the petioles
of every leaf on the shoot, with the exception of a few on the extremi-
ties of the side branches. At 12:30 P.M. samples were taken for
moisture determination.

TABLE 5

MOISTURE CONTENT OF LEAVES TO WHICH WATER WAS AVAILABLE FROM
TWO SOURCES

Hour picked	Weight of container and material in grams	Weight of same when dry in grams	Weight of material in grams	Average water content in per cent
8:30 A.M.	21.967	21.617	.562	. .
	23.455	23.162	.480	160.8
12:30 P.M.	21.914	21.659	.459	
	21.552	21.345	.382	121.6

The data obtained in this experiment show that during the night,
when the draught of the atmosphere on the water supply was low, the
leaves were able to maintain themselves in a normal condition by
using water from the base container. This is evidenced by the normal
water content of the leaves in the morning, as well as indicated by the
fact that no eosin whatever was drawn back, although the vascular
bundles were open to its entrance. However, as the atmospheric
evaporating power increased during the forenoon, it became more and
more difficult for the leaves to obtain requisite amounts of water
through the conducting system in the normal way. At a point near
12 M. the leaves became unable to obtain enough water in this fashion
and they began to draw on the aqueous solution of eosin. The shoot
was now drawing water from both ends to satisfy the demands of the
transpiring leaves. But the atmospheric pull for water became so
severe that even this double supply did not suffice to maintain the
water content of the leaves at normal. The water deficit began to
increase and continued until a condition of actual wilting resulted.
Between 8:30 A.M. and 12:30 P.M. the leaves decreased in water con-
tent by 39.2%, although both ends of the shoot were immersed in
water.

From the evidence above presented it seems clear that under con-
ditions favorable to rapid transpiration it is entirely possible for the
leaves of citrus trees, at least, to draw water back from the young
fruits. Moisture determinations of fruits under such conditions
showed a considerable decrease in water content and indicated that

this water is utilized by the leaves. Indeed, almost exact quantitative results were obtained, the percentage of water loss of the fruit being approximately equal to that gained by the leaves. (See Experiment 2.) Dye stuff experiments have shown that there exist no physical difficulties for such procedure. It then remained to determine whether this phenomenon actually occurred in fruits on the tree. For this purpose the procedure of the previous experiments was used, namely, moisture determinations and water transport studies by means of dye stuff solutions. However, the evidence here is not so conclusive, as all the experimental work was necessarily performed on shoots *in situ*, which introduces a number of uncontrollable adventitious variables, as has been well pointed out by Dixon[10] in his criticism of transpiration measurements performed on shoots detached from the tree. The influence of the remainder of the tree is admittedly an unknown quantity. Nevertheless it is believed that the data obtained are strongly indicative of conditions as they exist.

From table 1 it will be seen that there exists a considerable difference in water content between those fruits, destined to remain and mature when picked before and after noon. Fruits of this sort gathered in the morning averaged 12.5′′ more water than those gathered in the afternoon. As is mentioned in the footnote to table 1 this difference is probably considerably smaller than it should be on account of the larger size of the fruits used in the afternoon determinations. That this same condition obtains in those fruits destined to subsequent abscission is also shown in table 1. In this case the diffference is 22.2%. There are several ways in which a decrease of water content in the fruit can be explained: (1) the water is actually drawn back from the fruits by the leaves; (2) the normal supply to the fruits is considerably reduced by being appropriated by the leaves before it reaches the fruits; or (3) the transpiration ratio of the fruit to the leaves is markedly increased. If the fruit possessed no stomata and did not transpire, the first condition must hold. However, the fruit does possess stomata in some numbers and is actively transpiring at the same time as the leaves. Therefore it seemed advisable to make a cursory comparative study of the number of stomata per unit of area on the fruits and leaves and also of the ratio of transpiring area of the fruits and leaves situated immediately behind them. While the young fruit possesses stomata even before the style is exfoliated, stomatal counts showed that the number is comparatively small, rang-

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10 Transpiration and the ascent of sap in plants (London, MacMillan, 1914), pp. 120–125

ing between 50–100 per square millimeter as compared to 300–450 per square millimeter on the leaves. Measurements of the leaves situated within six inches of the fruit showed that, in addition the leaf area immediately behind the young growing fruit is larger than the area of the fruit until it reaches approximately two inches in diameter, after which falling of the fruit is comparatively rare. Therefore, it seems highly probable that the transpiration of the fruit as compared to that of the leaves situated immediately behind it is an almost negligible factor and it appears reasonably certain that either water is actually drawn back or that the normal supply is decreased.

Considering these two possibilities, the first merits more consideration as it is supported by proof which, though not absolute, is at least presumptive evidence of a strong enough character; while on the other hand the second possibility, agreeing though it does with the most recent theory on sap movements in plants as put forth by Dixon, is still a theoretical consideration. According to this theory, which postulates strong tensions existing in the ascending water columns, no assumption of an actual reversal of the current is necessary in order to explain a decrease in moisture content. During normal conditions the relation between the tensions existing in the water columns leading to the fruits and those leading to the leaves is such that both organs receive an adequate water supply. The tension existing in any one of these water columns is a function of the transpiring force existing in the transpiring plant organ as modified by atmospheric conditions. Therefore, as these transpiring forces vary, the tensions vary. Transpiration from the leaves, for reasons pointed out above, is subject to much greater variation than that from the fruits. Therefore during periods when evaporation is greatly accelerated the tensions in those water columns leading to the leaves are greatly increased and as a consequence more water is drawn to them. As the source of supply in the conducting system is practically constant, the amount in the fruits is thereby reduced and this results in a decrease of relative water content of a magnitude conditioned by the transpiration of the fruit.

However, it should be noted that the data in table 1 show a decrease in absolute water content of the fruit of 15% to 20%, a loss of considerable magnitude. There are only two ways in which such a decrease in absolute water content can take place: (1) the water is lost by transpiration from the fruit, or (2) it is drawn back by the leaves. But since the fruit possesses a very small stomatal area

as compared with the leaves and, moreover, it is highly probable that a large percentage of this area is non-functional, being obstructed by accumulations of a resinous nature, there is small likelihood for absolute loss of water in this manner to the extent noted. Hence there seems but one way to explain it and that is by movement back from the fruits.

Evidence of an indirect nature pointing to the same conclusion lies in the fact that there are some indications that abscission of a certain proportion of the young fruits is directly due to the influence of hydrolysing enzymes secreted by certain saprophytic or facultative parasitic fungi always found present on the shriveled style and frequently in the proliferations of the navel. Such enzymes in order to act on the abscission layer must be drawn back through the vascular systems of the fruit into the pedicel where this layer is located. Investigations on this point are now in progress.

Experiment 7—Three similar fruits were selected on different parts of a tree; on one of the lower branches in the shade, at a height of four feet, and in the top of the tree in full sunlight. At noon each fruit was pared so as to admit entrance of a solution and then plunged quickly into a small vial containing a watery solution of eosin. These vials were securely tied to the shoot and left suspended for two hours. At the end of that time, on cutting leaves from these shoots, eosin staining was found in the vascular systems of all. On examining backward toward the tree, eosin was found as far back as thirty centimeters. This experiment was repeated a number of times both at Edison and at Riverside and uniformly gave the same results, although much less marked at the latter place. In every case the backward movement of the eosin solution was at its maximum during the afternoon.

Cutting the ends of branches *in situ* under a watery solution of eosin was tried at different times of day and gave similar results. This experiment was performed at Edison, Riverside and Indio. At the latter place, with the temperature at 116° F and the humidity at 8%, the eosin solution traveled backward at the astonishing rate of 30 cm. per minute at 6 P.M. Similar results were obtained using *Eucalyptus rudis* as material. In fact with long slender poles of *Eucalyptus tereticornis* at Edison, such a remarkably rapid backward flow of eosin was observed (105 cm. in one minute) in the afternoon as to compel the conclusion that after all, the force responsible for this movement under such conditions must be negative pressure pro-

duced by rapid transpiration rather than a mere difference in osmotic concentration of the solutions involved. Moreover, negative pressure produced by transpiration would seem a more plausible explanation of the results obtained by Chandler[11] with tomato plants and by him attributed to osmosis. For as Dixon[12] has pointed out "it is quite possible for the solvent, water, to be in a state of tension, i.e., at a negative pressure, while the dissolved substance may be at a positive pressure and be active as a distending force in the cell."

These experiments, it is believed show that, during the afternoon at least, strong negative pressures exist in the water columns of citrus trees under the climatic conditions here considered and that the young developing fruits are deprived periodically of a part of their water supply by excessive transpiration from the leaves.

During the June-drop period of 1916 a number of holes were dug in various parts of the Edison orchard to a depth of six feet and moisture determinations made at various depths and on all sides of the tree. The moisture content was found to range between 5% 6% just before irrigation and between 10% -12% soon after irrigation. A fruit grower observing this soil and the vigorous growth of the trees would hardly conclude that the trees were suffering from lack of water. However, the specific effect of variations in the moisture content of the soil on the transpiration rate and water content of orange leaves has not yet been carefully determined. While there is little room to doubt that the above-ground complex is more important in influencing transpiration than the below-ground complex, still it is entirely possible that this abnormal water deficit in the leaves and fruit may be more easily induced by sudden changes in the climatic complex under conditions of a deficient moisture supply in the soil or, what amounts to the same thing, an inhibition of the normal absorption due to lack of sufficient aeration or excessively high soil temperatures. Nevertheless evidence is not lacking that marked changes in air temperature and humidity may be sufficient to cause abscission of young fruits even though the soil moisture conditions be ideal. Such apparently is the explanation of the heavy drop of Washington Navels already referred to, which occurred over most of the citrus districts immediately following the excessive temperatures of June 15–17, 1917, when the mercury reached 110–120° F in many parts of the citrus district south of the Tehachapi mountains.

[11] Mo. Sta. Res. Bull. 14, pl. 13.
[12] *Loc. cit.* p. 140.

Conclusion

This paper deals with one phase of an investigation of a so-called physiological disease, June drop of the Washington Navel orange. An excessive dropping of the young fruits has been experienced for years in the dry interior valleys of California and Arizona.

An abnormal water relation is found to obtain periodically in citrus foliage and in the young fruits during the hot growing season in these regions. A diurnal decrease in water content of the fruits occurs during the afternoon and is accompanied by a considerable increase in the water deficit of the leaves. Negative pressures of considerable magnitude are found in the water columns of citrus trees under these climatic conditions. These attain their maximum during the afternoon. The dropping of the fruits appears to be most severe where the above mentioned water relations are most abnormal.

Inasmuch as in the case of certain other plants the abscission of young fruits has been shown to be due to abnormal water relations it is suggested that such may be the case here.

In conclusion, the writer wishes to acknowledge his indebtedness to Professor J. Eliot Coit, under whose supervision and with whose assistance a large part of the experimental work was done; also his obligations to Professor Charles B. Lipman for his kindly interest in the investigation and for his many useful suggestions, and to the Edison Land and Water Company for their kind and courteous coöperation.

PLATE 12

Fig. 1. Showing extent to which the leaves can draw on the water in the fruit. Both shoots were cut at the same time and had approximately the same leaf area. All cuts were sealed with vaseline. The fresh-appearing leaves on the shoot at the left have maintained themselves at the expense of water in the fruit. Note the difference in reflection of light from the two fruits. See Experiment 1.

Fig. 2. Photograph illustrating an orange shoot so arranged as to be able to draw water from one end and eosin solution through the pared apex of a small fruit at the other. In spite of this double supply a large water deficit occurred, and eosin was drawn back from the container on the right to the leaf next to the water container on the left. See Experiment 6.

Fig. 1

Fig. 2

A NEW DENDROMETER

BY

DONALD BRUCE

UNIVERSITY OF CALIFORNIA PUBLICATIONS

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A NEW DENDROMETER

BY

DONALD BRUCE

There is a growing demand for a satisfactory dendrometer, or instrument which will measure the diameter of trees at points out of reach from the ground. An indication both of the wide demand and of the requirements which such an instrument must meet may be gained from a consideration of the following instances.

In certain regions, United States Forest Service timber estimators have made use of a volume table based on a diameter measurement at the top of the first sixteen-foot log instead of at the conventional breast-high point. This was on account of the abnormal form of the badly burned butts, which made a lower measurement both uncertain and a poor index of volume. Considerable trouble resulted through inability to check the ocular estimates of diameters except by uncertain methods of measuring at breast height and subtracting the estimated taper. For such cases there is needed a dendrometer of moderate precision, large range, considerable rapidity, lightness, and portability.

Many volume tables are based on a measurement of height to a certain fixed cutting limit, such as six, eight, or ten inches top diameter. From the ground it is often more difficult to identify this point than it is to estimate its height, and considerable errors result. Instruments of only a small range of sizes are needed, and in fact for a given volume table, or a consistent set of tables, an instrument that can be fixed and adjusted for a single diameter would serve the purpose.

Other volume tables are based on height to the limit of merchantableness. This limit, however, varies widely in different regions, even for a single species, and to use such a volume table accurately one must know the top diameter corresponding with each value of the table and estimate heights accordingly. Exactly the same type of in-

strument is required as in the last case, save that a slightly larger range of diameters is needed and a fixed adjustment for a definite size is not adequate.

Many Pacific coast volume tables are based on diameter, height, and taper. While the first two factors are measured, at least occasionally, the last is usually a matter of guesswork entirely. The instrument needed to strengthen this part of the work is a dendrometer possessing the qualities above mentioned, and in addition one which works independently of distance, since both horizontal distances and heights will usually be but roughly approximated.

In many scientific studies of growth on permanent sample plots in this country periodic measurements of diameters breast-high and
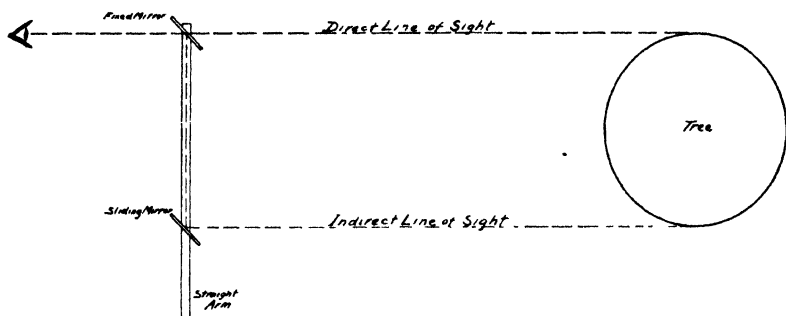
Fig. 1

heights are being secured, and growth in volume is being calculated from these data by means of a single volume table for each species. As a result, whatever growth results from a change in tree form is being neglected. A dendrometer is needed of considerable precision, but not necessarily so portable or rapid in action as in the previous cases. Its range in most cases need not be great, since the more important growth problems are connected with second-growth timber or, at least, with trees below a certain diameter limit.

Schiffel's formula for obtaining volume has not been sufficiently tested for most American species, but it is regarded as probably having a high value in many cases. It requires a measurement of diameter at a point half way up the bole, and hence a dendrometer. The qualifications of a satisfactory instrument will naturally depend on the character of the work being done.

All these instances indicate that it is not due to the absence of a real need that dendrometers are practically unknown in America. It seems obvious, rather, that no existing type satisfies the conditions

above outlined. The following pages describe an instrument based on a somewhat different principle from those previously devised, which will be seen in a large measure to meet these requirements.

It consists essentially of a straight arm upon which are mounted two small mirrors, both at an angle of 45 degrees with the axis of the arm, parallel to each other and facing in opposite directions (see fig. 1). One mirror is fixed at one end of the arm, while the other is mounted on a slide which travels along the arm. Graduations permit a direct reading of the distance between the mirrors.

The principle is indicated by figure 1 which shows the relative position, as seen from above, of tree, observer's eye, and of the instrument when in use. It will readily be seen that the instrument is closely akin to the ordinary calipers in principle, except that for the parallel fixed and movable arms of the calipers are substituted two parallel lines of sight. The direct line of sight passes just above the upper edge of the fixed mirror from eye to one edge of the tree, while the indirect line of sight is reflected in each of the two mirrors to the other edge of the tree. That the two lines of sight are parallel and hence that the distance between the mirrors is equal to the diameter of the tree is too self-evident to demand geometrical demonstration.

In use the observer holds the dendrometer arm horizontal (if the tree is in the normal vertical position) with one of the mirrors in line between his eye and the left-hand edge of the tree at the point to be measured. He then catches the reflection of the second mirror in the first, thus bringing the arm into a line perpendicular to the line from eye to tree. By sliding the second mirror in or out, the right-hand edge of the tree will become visible in it. The adjustment is now continued until the left-hand edge as seen directly and just above the fixed mirror, and the right-hand edge as seen indirectly through the two mirrors, are in a straight line, one immediately above the other. The distance between the mirrors as read from the graduations on the arm is then the required diameter.

The advantages and disadvantages of the instrument are evident.
   a. It is direct reading.
   b. The distance from the observer to the point observed does not have to be determined.
   c. As a result, the instrument is rapid in use.
   d. It may be set for a given diameter, regardless of distance.
   e. It is light in weight and of convenient shape for carrying; it is more portable than a pair of calipers of the same range.

f. It will measure only a moderate range of sizes.

g. While very accurate for a hand instrument, it is not capable of extreme precision.

The reason for the last two statements will be explained in the following pages.

It is evident that it will meet quite well the requirements already outlined. It fails at two points only—its moderate range might prevent its use in very large timber, and its lack of absolute accuracy may militate against it for very precise, scientific work.   •

Most of the errors of such a dendrometer are easily kept negligible. Of course at any considerable distance, small variations of diameter are imperceptible and cannot be measured. Since the minimum visual angle for normal eyes is one minute, two-tenths of an inch is the smallest variation recognizable at a distance of fifty feet. This consideration applies equally to all dendrometers which do not involve telescopic observations, and the use of a telescope at once means a heavy and awkward instrument.   .

If the arm is not held at right angles to the direct line of sight, the graduations on the arm will no longer measure the distance between mirrors along the indirect sight line, nor will this distance agree with the desired diameter. However, this error can never be large since, unless the arm is in approximately the correct position, the second mirror cannot be seen at all in the first, and to center its image therein is an instinctive proceeding. For more precise work, however, an additional aid may be afforded by vertical lines scratched into the backing of each mirror at its exact center, which are to be brought into apparent coincidence when the instrument is in use. An alternative method of obtaining the same result is to mask the fixed mirror with dark paper until, at the most convenient distance from the eye, the whole of the movable mirror can just be seen in it. The position of such a mask is shown in figure 2, *A*.

A rotation of the dendrometer about the axis of the arm will, of course, raise or lower the indirect sight line running from the instrument to the tree. Here again, however, unless the position is essentially correct, the image of mirror 2 cannot be found in mirror 1. The error resulting, moreover, is merely the amount of taper that occurs between the points observed by the direct and indirect sight lines, which is usually negligible.

Of course, if the two lines of sight are not parallel, serious errors will result. This depends on having the two mirrors parallel and is

in part a matter of adjustment. Two opposed adjusting screws must therefore control the rotation of one of the two mirrors. Adjustment is simple Some target of known diameter or breadth (a sheet of paper against a dark background will serve) is observed with the instrument set at the corresponding diameter. The mirror is then rotated by its adjustment screws until the two edges appear in line. This process is delicate, but neither complicated nor difficult.

A- *Assembled Dendrometer Elevation*

B- *Plan*

C- *Cross Section of Arm*

D- *Slide from below*

Scale for A B and C

Scale for D E and F

E *Slide Elevation*   F- *Slide from end*

a.—Arm.
b.—Stationary mirror platform.
c.—Sliding mirror platform.
d.—Slide.

e.—Fixed mirror and support.
f.—Adjustable mirror and support.
gg.—Adjustment screws.
h, i.—Springs.
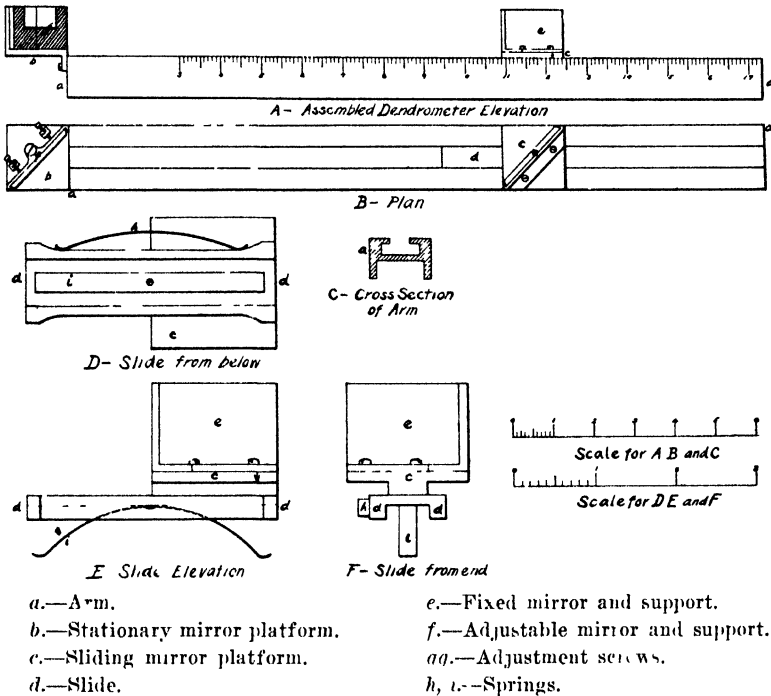
Fig. 2

The one error which dominates all others is that due to a failure of the arm to be absolutely straight. This is unfortunately a matter of instrumental construction and not of adjustment, and the difficulty of making this arm straight is surprisingly great. It is obvious that almost imperceptible deviations will result in slightly diverging or converging sight lines and in increasingly serious errors in the diameter readings, as the distance at which the measurement is taken is lengthened. In the instrument described the maximum error from this source is .6 inch when used at fifty feet; it is doubtful if materially better results are obtainable. This is not excessive. Even with a transit read to the nearest minute, the diameters fifty feet away can be read

but to the nearest .2 inch. With a hand instrument of the common type which involves the measurement of the angle between two sight lines it is difficult to provide for an accurate reading closer than to the nearest 10 minutes. This means that at the same distance 1.7 inches would be the minimum recognizable difference in diameter.

Figure 2 shows the details of construction.[1]   *a-a,* of *A, B,* and *C,* is the straight arm which is made of a casting of aluminum alloy. The straight edge is the back surface of the slot which is recessed into the upper surface of the arm, as is best seen in the cross-section. This cross-section is perhaps unnecessarily heavy, but was so designed to insure as perfect a straight edge as possible. In this slot travels the slide *d* shown in detail in *D, E* and *F,* which are drawn to twice the scale of *A, B* and *C.* This slide is equipped with two springs, *h* and *i,* which hold it against the back and upper surfaces of the slot. Upon
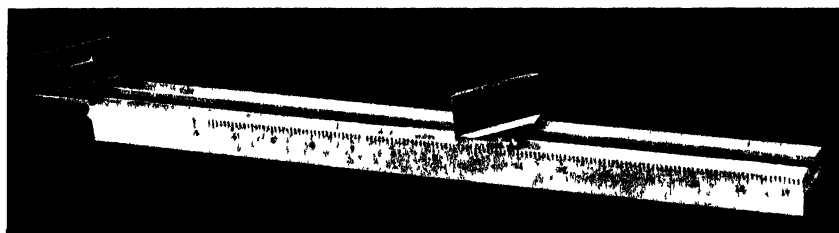
Fig. 3

it is mounted the mirror platform, and mirror *c* turned to an angle of 45 degrees to the axis of the slide. At the end of the arm a second fixed mirror platform, *b,* is mounted on which is the second mirror. *f,* which can be adjusted by the two opposed adjusting screws, *g-g.* This mirror is shown with both center line and mask, though both are hardly necessary. The scale is readily seen in *A.* This is read by means of the small arrow engraved on the side of *c,* as shown in both *A* and *E.* In *A* the reading, for example, is 12.2 -.

If the weight of the instrument, slightly less than 27 ounces is found objectionable, it would probably be safe to lighten materially the cross-section of the arm by reducing both the depth of the downward projecting ribs and the thickness of the lateral walls. The mirrors also, as shown, are very generous in size, and might be reduced to about two-thirds the indicated dimensions without introducing any serious difficulties through restricting the field of vision.

The instrument shown has an arm eighteen inches long and will read diameters from three to seventeen inches. A longer arm is, of course, possible, but at about thirty inches a point is reached at which the adjustment of the sliding mirror when held in working position would become awkward. This may then be taken as the practical limit, unless some modification of the principle be adopted. This range will be sufficient for a great deal of the work to be done. If less accuracy is required, measurements of double this size can be secured by taking the center of the tree as the target for the direct line of sight, instead of the left-hand edge, and bringing the reflection of the right-hand edge in line with the center point. This operation can be performed more accurately than might at first be supposed, and the method, while rough, is probably quite adequate for work in connection with the Pacific coast volume tables already mentioned, in which taper is a factor.

A quick field test of the parallelism of the sight lines consists in measuring the same diameter at two different distances. The readings should, of course, be identical, or rather, since a small observational error is unavoidable, as nearly identical as would be two consecutive measurements from a single position. If an error is found and it is not convenient to make the proper adjustment it may be simply and quite accurately allowed for, by taking consecutive observations at two known distances. For example, suppose the first reading is 14.8 inches and the second reading taken at one-half the distance is found to be 14.4 inches. Since the error is proportional to the distance, a reduction of the distance to one-half must also reduce the error to one-half. The reduction in error is .4 of an inch, the total original error must have been .8 of an inch, and the correct reading is therefore 14.8 — .8 = 14.0 inches. Where the errors are small, the major portion of them can thus be eliminated, even if the distances are estimated instead of measured.

A modification of this type of dendrometer is suggested for timber survey crews which are using volume tables to a fixed top-cutting limit such as six or eight inches. All that is necessary in such cases is the pair of parallel mirrors, one of which is adjustable, mounted six or eight inches apart on any light but rigid base not affected too readily by changes of temperature or humidity. By thus eliminating the straight edge and slide of the instrument herein described, the most serious source of error will be eliminated and the cost largely reduced.

TOXIC AND ANTAGONISTIC EFFECTS OF SALTS ON WINE YEAST *(SACCHAROMYCES ELLIPSOIDEUS)*

BY

S. K. MITRA

UNIVERSITY OF CALIFORNIA PUBLICATIONS

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BY

S. K. MITRA

CONTENTS

INTRODUCTION

Most of the published studies of wine yeast deal with its activities as related to wine making. Its botanical characteristics and still less its fundamental physiological reactions have apparently received little attention. Among the most important and interesting investigations of higher plants, bacteria and animals in recent years have been studies of the effects of various single salts and various combinations of salts on the physiology of these organisms. For example, it has been found by Osterhout[6, 7] that practically all of the simple salts, such as sodium chloride, potassium chloride, calcium chloride, etc., have a decided toxic action upon the plant when it is subjected to the action of a single pure salt. Further, if certain combinations of two or more salts were used in certain ratios the toxicity was reduced. This reduction of toxicity is commonly termed antagonism between the salts used. It was found also that a combination of all the salts in the ratios in which they occur in the soil solutions or in other solutions to which the plant is accustomed afford the best conditions for growth. Such a combination is spoken of as a physiologically balanced solution.

Loeb working with marine animals and C. B. Lipman with soil and other bacteria obtained results similar to those obtained by Osterhout with the higher plants. As was to be expected, the reaction of animals to the salts was not identical with that of bacteria, nor does either reaction follow the behavior of the higher plants closely. In

general, however, the results with all three classes were of the same kind; that is, single salts, hitherto considered non-toxic, were found to be toxic to organisms, while various combinations of these salts showed antagonism or reduction of toxicity in the presence of each other.   In accordance with these facts, a physiologically balanced solution can be made by using proper concentrations and proportions of the various salts found in the solutions to which the organism is accustomed.

So far as the writer could ascertain, no one has investigated the behavior of yeast in this respect.   Results of investigations of the effects of the heavy metallic salts, such as mercuric chloride, silver nitrate, etc., on yeast have been published (Bokarny[12]), but nothing has appeared upon the toxic and antagonistic effects of such salts as sodium chloride, potassium chloride, calcium chloride, and magnesium chloride.   This field therefore seemed especially inviting, and it was with the idea of studying the fundamental relations existing between yeast and the chlorides that the writer undertook the work summarized in the following pages.

Acknowledgments

Method of Experimentation

In the selection of a yeast for my investigation I was led to use the wine yeast, *Saccharomyces ellipsoideus*, by the fact that it is one of the most useful of all yeasts and is universally used in wine making. It is also one of the most vigorous, is easy to grow, and gives definite results in a few days.

The particular yeast, no. 66, used in this experiment, was isolated by William V. Cruess from one of the wineries in northern California. It has been found by repeated trials that specimens of *Saccharomyces ellipsoideus* collected from different sources are not identical as to their physiological characters in every respect. and so do not respond in different salt solutions in the same way.   An experiment showing this will be described later.

Although work on this line may not have immediate practical

value to the zymologist, it is of considerable scientific interest. It is with this thought that these experiments have been carried out in the Laboratory of Zymology.*

The salts tested in these experiments were the chlorides of potassium, magnesium, calcium and sodium, each being taken up separately. The reason for choosing these chlorides was that their metallic ions (cations) are·those most abundant in the ash of grape juice. Besides, Loeb[1] and Lipman[11] have shown that the positive ions of these salts have the most effect, while their negative ions (anions) have the least. Owing to the fact that the effect of the chlorine ion is uniform in all cases, the metallic ions show their characteristic effects on the yeast culture very clearly.

Choice of Solution.—It has been shown by Loeb with marine animals (*Fundulus*), by Osterhout with higher plants (wheat), and by Lipman with soil bacteria (*Bacillus subtilis*) that, for the growth of living organisms, a nutrient solution must be physiologically balanced. In order to grow the yeast in a medium whose constituents were known both in quality and quantity, it was necessary to prepare a nutrient solution from pure materials. Such a solution must contain an adequate amount of nitrogen and phosphorus in order that the yeast may grow rapidly. For this purpose a number of substances were tried, such as Witte's peptone, asparagin, urea, and ammonium phosphate, in different concentrations, with pure cane sugar or pure dextrose. Witte's peptone proved to be impure, being very high in ash, and the others did not give satisfactory results. As dextrose is not easily available in the market at present, pure cane sugar had to be used as a carbohydrate food and as a source of fermentable material.

Later a synthetic solution was made with hydrolized pure cane sugar, phosphoric acid, and ammonia. which was suitable for the growth of yeast for experimental purposes. Although this synthetic solution produces a slower rate of growth than grape juice, which is a perfect physiologically balanced solution for yeast fermentation, it gives sufficient growth for experimental work. To make it, a 50 per cent pure cane sugar syrup was made with distilled water and a measured amount (1 gram per 100 c.c. of syrup) of phosphoric acid added. This syrup was hydrolized by boiling for one-half hour on a slow fire, and was then neutralized with dilute ammonium hydroxide. Litmus solution was used to test the neutrality of the syrup. The

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* These experiments were carried out under the general supervision of William V. Cruess.

ammonium phosphate that eventually formed furnished both the nitrogen and phosphorus needed by the yeast. As yeast cells grow easily in moderately acid, but not in alkaline solutions, the syrup was left slightly acid, being tested by titration with N/10 solution of sodium hydroxide. To facilitate the work, the syrup was boiled down to 65°Balling and put into a corked bottle. From this concentrated synthetic solution a measured quantity was drawn off and diluted with distilled water to 5°Bal. for use in the cultures.

Method of Determining the Activity of the Yeast.—The experiments were carried on in a series of 200 c.c. Erlenmyer flasks. To each flask the weighed amount of salt was added and 100 c.c. of the diluted synthetic solution placed in the flask by means of a 100 c.c. pipette.

The salts were weighed according to their respective molecular concentrations. The flasks as soon as filled were plugged with cotton and sterilized. After they had cooled down to the room temperature they were inoculated with the yeast from a new culture. For this purpose the new culture was prepared in a 200 c.c. Erlenmyer flask containing 100 c.c. of the synthetic solution. The yeast thus became habituated to this solution and therefore grew rapidly and uniformly in the flasks. The new culture was transferred from a mother culture in grape juice and put into the incubator for forty-eight hours at 28°C. At the end of this period the flasks containing the salts were inoculated with one cubic centimeter of the new culture. After inoculation, the flasks were put into the incubator, which was kept at an approximately even temperature of 28°C. during the entire experiment.

As the alcoholic fermentation in the synthetic solution was not rapid enough to serve as a criterion, the multiplication of the cells was taken as the measure of the activity of the yeast. Accordingly a microscopical count was made every forty-eight hours with a calibrated microscope. Five counts were made in each experiment, during a period of about twelve days. In every case two blanks, with no added salts, were made up, and the tables given represent the average of two sets of duplicate experiments, except in the cases of potassium chloride and magnesium chloride, where the results were so close that only the first set of duplicates was used. It may be added that the incubator did not keep exactly the same temperature throughout the experiments, but ranged from 27°C. to 29°C. This difference of 2°C., however, did not interfere appreciably with the uniformity of growth

and the check flasks controlled any slight variation it may have caused.

Salts Used.—During February, 1916, a series of experiments in two parts was planned. The first concerned the toxicity of the single salts and the second the antagonistic effects of all their binary and ternary combinations, as follows:

I. TOXICITY OF THE SINGLE SALTS

1. KCl   3. CaCl₂
2. MgCl₂   4. NaCl

II. ANTAGONISTIC EFFECTS OF COMBINATIONS

A. Binary Combinations

1. MgCl₂ + CaCl₂   4. KCl + NaCl
2. KCl + CaCl₂   5. KCl + MgCl₂
3. MgCl₂ + NaCl   6. CaCl₂ + NaCl

B. Ternary Combinations

1. NaCl + KCl + CaCl₂   3. NaCl + MgCl₂ + CaCl₂
2. NaCl + KCl + MgCl₂   4. KCl + CaCl₂ + MgCl₂

A. EXPERIMENTS WITH SINGLE SALTS—TOXIC EFFECTS

In all cases chemically pure salts (Baker's analyzed) were used. Each amount of the single salts was carefully weighed and put into the flasks, except .001M and .01M, which were added as solutions of known strength according to molecular weights. The following proportions were taken:

1. KCl — .001M to 2.2M* Molecular
2. MgCl₂ — .001M to 1.2M
3. CaCl₂ — .001M to .7M
4. NaCl — .001M to .2M

All of these solutions were clear except the calcium chloride, which gave an appreciable amount of coagulated precipitate of calcium phosphate with the phosphorus of the synthetic solution. This, however, did not interfere with the experiment, as the precipitate disappeared with the growth of the yeast and the solution finally became almost clear. The tables and curves given in each case show the growth of yeast at every forty-eight hours in the different molecular concen-

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* M represents the degree of concentration in a solution which contains one gram molecule of the substance in one litre of solution.

trations of each salt as indicated above. In the microscopical count one million yeast cells per cubic centimeter was taken as an appreciable number; below that it was not considered that any appreciable growth had taken place.

SERIES I—POTASSIUM CHLORIDE

Thirty 200 c.c. Erlenmyer flasks were arranged in duplicate, including two blanks. The first pair had no salt added and was used as a check. The second pair had .001M KCl and the third .01M KCl, and so on to the last pair, which had 2.2M KCl, as shown in the table below. Then, with a 100 c.c. pipette one hundred cubic centimeters of the diluted synthetic solution (5°Bal.) were put into each flask. The flasks were plugged with cotton, sterilized, and inoculated with yeast, as stated before, and put into the incubator, and counted every forty-eight hours. The results are shown in table 1 and the curves in figure 1.

The curves have been plotted from the results of every forty-eight hours' growth, taking the various concentrations of potassium chloride as abscissae and the number of yeast cells, counted in millions, as ordinates (fig. 1). Following the table and the curves, it is evident at a glance that potassium chloride up to the concentration of .2M accelerates the multiplication of the yeast. Beyond this it becomes gradually more and more toxic until at 2.2M the yeast cells entirely cease to multiply. Both Magowan[10] and Lipman,[11] especially the former, found a strong resemblance between potassium chloride and sodium chloride in their action on wheat and on *Bacillus subtilis*. The yeast shows physiological characteristics differing from those of either the bacteria or the wheat.

Lipman[11] found sodium chloride the least toxic to *Bacillus subtilis* and potassium chloride second. Magowan,[10] with wheat, found this position reversed, the potassium chloride being less toxic. Both observers found that these salts were very similar in their degree of toxicity. To yeast sodium chloride is the most toxic of the four salts and potassium chloride the least. Ostwald[4] in experimenting with animals (*Grammarus*) found potassium chloride the most toxic, and Loeb's work[2, 3] with *Fundulus* corroborates this to a certain extent. The reaction of yeast, therefore, differs from that of bacteria of the higher plants or of animals.

TABLE 1—TOXIC EFFECT OF KCL ON *Saccharomyces ellipsoideus*

M.KCl	48 hrs	96 hrs.	144 hrs.	192 hrs.	240 hrs.
.00	1,695,000	7,237,000	11,636,000	12,892,000	15,835,000
.001	3,325,000	10,786,000	15,400,000	16,217,000	19,670,000
.01	7,797,000	15,600,000	18,905,000	21,479,000	23,568,000
.1	7,262,000	20,558,000	24,208,000	24,608,000	27,915,000
.2	5,650,000	18,493,000	29,689,000	28,783,000	30,541,000
.4	5,425,000	20,227,000	25,006,000	27,560,000	28,914,000
.6	1,130,000	8,535,000	20,928,000	22,802,000	23,802,000
.8	809,000	5,298,000	17,670,000	19,508,000	20,982,000
1.0	226,000	6,787,000	15,205,000	17,986,000	18,453,000
1.2	....	1,102,000	8,986,000	16,207,000	16,951,000
1.4	....	452,000	8,765,000	11,584,000	12,882,000
1.6	....	....	3,204,000	5,794,000	8,232,000
1.8	....	....	904,000	1,243,000	6,252,000
2.0	....	.. ..	....	904,000	2,051,000
2.2	....	....	....	... ...	226,000
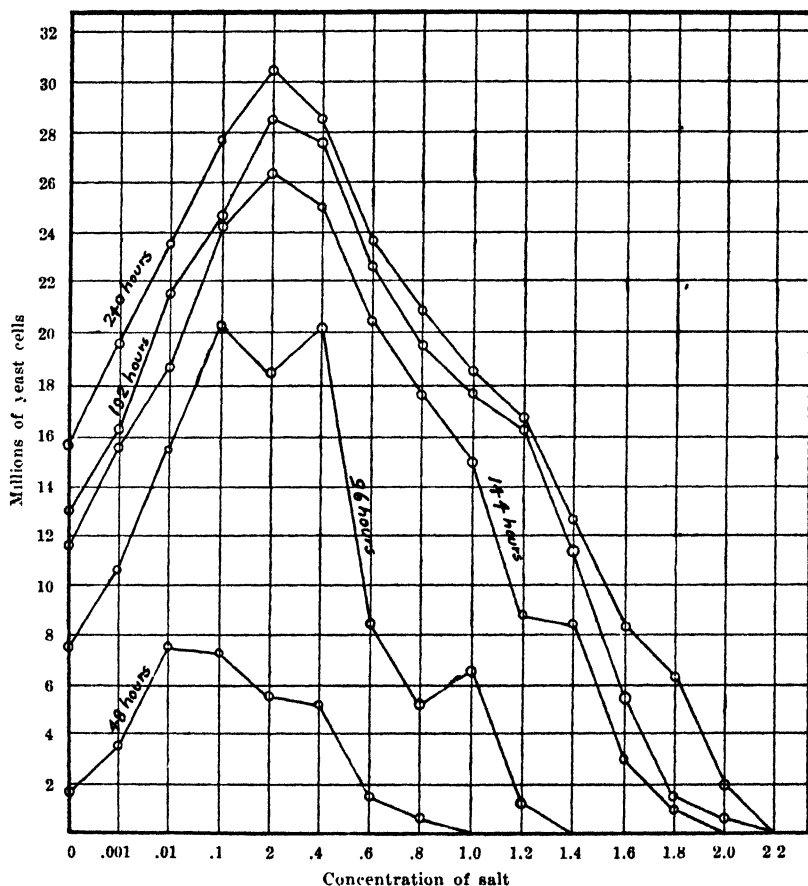
Fig. 1.—The ordinates represent millions of yeast cells and the abscissae, the various concentrations of KCl. The ordinates at 0 represent the number of yeast cells in the check cultures.

SERIES II—MAGNESIUM CHLORIDE

The same method of procedure was used with $MgCl_2$ as with KCl. The results are shown in Table 2.

TABLE 2—TOXIC EFFECT OF $MgCl_2$ ON *S. ellipsoideus*

M MgCl₂	48 hrs	96 hrs	144 hrs.	192 hrs	240 hrs
.00	2,412,000	8,108,000	12,205,000	16,837,000	17,202,000
.001	4,972,000	10,753,000	13,673,000	18,871,000	19,775,000
.01	8,751,000	15,798,000	18,703,000	19,588,000	20,374,000
.1	3,482,000	12,227,000	20,521,000	25,013,000	26,501,000
.2	2,356,000	7,204,000	11,342,000	15,530,000	18,617,000
.4	1,695,000	5,400,000	9,504,000	12,837,000	17,413,000
.6	989,000	2,157,000	7,332,000	11,253,000	11,905,000
.8	226,000	1,130,000	4,294,000	6,943,000	8,436,000
1.0		226,000	1,875,000	2,712,000	2,904 000
1.2					226,000
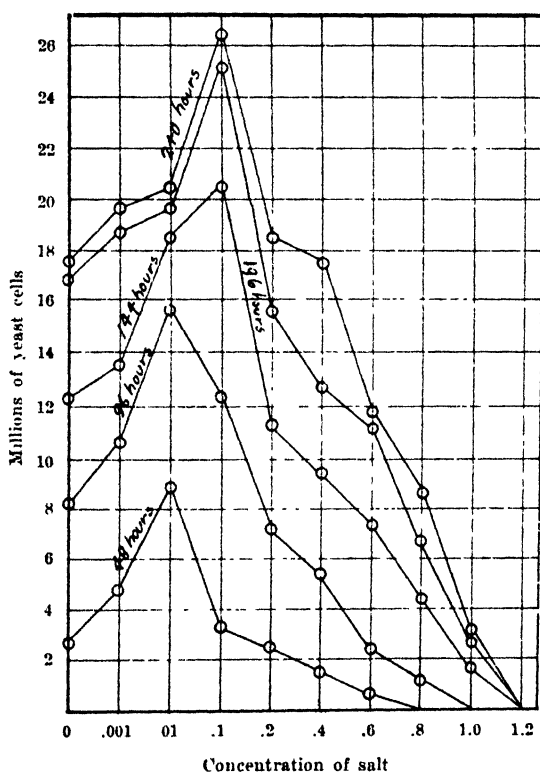
Fig. 2.—The ordinates represent the number of yeast cells in millions and the abscissae, the concentration of magnesium chloride. The ordinate at 0 represents the number of yeast cells in the check cultures.

From both table 2 and the curves in figure 2, it is evident that magnesium chloride is more toxic than potassium chloride. Up to the concentration of .1M, it is favorable to the growth of yeast, but beyond this it becomes more and more toxic until at 1.2M concentration there is little or no growth at all. In the case of yeast, magnesium chloride and calcium chloride show less similarity than that found by Lipman with soil bacteria, and the toxic effect of magnesium chloride is nearer to that of calcium chloride than to that of potassium chloride. Magnesium chloride is not so toxic to yeast as Lipman found it with *Bacillus subtilis*. In the case of yeast, .7M concentration of calcium chloride altogether inhibits its growth. The same concentration, however, of magnesium chloride allows an appreciable number of yeast cells to grow, and the same toxic effect as that of .7M $CaCl_2$ is not attained until a concentration of 1.2M $MgCl_2$ is reached. In fact, magnesium chloride stands midway between the two extremes of toxicity of these four salts, namely, the more toxic $NaCl$ and $CaCl_2$ and the less toxic, KCl.

Loeb,[1, 2] with marine organisms, found that a .5M solution of magnesium chloride inhibits the development of embryos in the eggs of *Fundulus*, and that even .125M $Ca(NO_3)_2$ is toxic. In his experiment with soil bacteria Lipman[11] has met with about the same result. He found that .4M $MgCl_2$ inhibits the growth of *Bacillus subtilis*, while for the same effect on yeast a concentration of 1.0M $MgCl_2$ is needed. But Magowan[10] has shown that with wheat magnesium chloride is the most toxic of all the four salts; in this respect yeast resembles neither the animals, nor bacteria, nor the higher plants.

It must be noted that the magnesium chloride used in all the experiments was $MgCl_2.6H_2O$, as this is less hygroscopic than the same salt having two molecules less of water ($MgCl_2.4H_2O$), which is difficult to weigh accurately. However, magnesium chloride was found more toxic than potassium chloride and more favorable than calcium chloride, which is directly opposite to the result obtained with higher plants.

SERIES III—CALCIUM CHLORIDE

The experiment with calcium chloride was carried on in the same way. From both table 3 and the curves in figure 3, it is evident that .01M concentration of $CaCl_2$ gives the highest growth, while beyond this favorable concentration $CaCl_2$ is more and more toxic. In its

toxicity to yeast, $CaCl_2$ stands second, NaCl being the most toxic of the four salts. A .5M concentration of $CaCl_2$ allows an appreciable growth of yeast, while even .2M NaCl stops all growth.

TABLE 3—TOXIC EFFECT OF $CACL_2$ ON *S. ellipsoideus*

M. CaCl₂	48 hrs.	96 hrs.	144 hrs.	192 hrs.	240 hrs.
.00	2,599,000	8,136,000	11,752,000	13,108,000	16,336,000
.001	3,051,000	9,989,000	12,656,000	13,965,000	17,751,000
.01	3,503,000	11,050,000	13,926,000	15,885,000	19,251,000
.1	226,000	6,034,000	8,468,000	10,904,000	16,674,000
.2	....	1,695,000	3,256,000	3,821,000	15,778,000
.3	....	904,000	1,130,000	3,090,000	14,561,000
.4	....	226,000	904,000	1,130,000	9,771,000
.5	....	....	226,000	987,000	2,935,000
.6	....	....	....	226,000	904,000
.7	....	....	....	....	226,000

Fig. 3.—The ordinates represent the number of yeast cells in millions and the abscissae the concentration of $CaCl_2$. The ordinate at 0 represents the number of yeast cells in the check cultures.

The work of other investigators with regard to the toxicity of $CaCl_2$ shows a general agreement with the results obtained by Loeb with *Fundulus*,[3] Ostwald[4] with fresh water, *Grammarus*, and Lipman[11] with soil bacteria, all of which show $CaCl_2$ to be extremely toxic. An exception to this general statement is found in the work of

Magowan, who showed in her experiments that, in the case of wheat, CaCl₂ is the least toxic of the four salts. Here also we find that yeast exhibits a peculiar physiological character which does not agree with either of the above divisions, the animals or the plants. Perhaps this may throw some light on the relation of yeast to these two groups.

SERIES IV—SODIUM CHLORIDE

As NaCl is the most toxic of all the salts, only a few pairs of flasks were taken, from .001M to .2M concentration, together with a pair of blanks. The experiment was carried on in the same way as the others. From table 4 and the curves in figure 4 it is evident that NaCl is the most toxic to the yeast. Even the concentration of .01M NaCl did not stimulate the growth of yeast, as it did with the other salts. The highest growth in this case was in .001M, and beyond that it was toxic.

TABLE 4—TOXIC EFFECT OF NACL ON *S. ellipsoideus*

M NaCl	48 hrs	96 hrs	144 hrs	192 hrs	240 hrs
.00	2,424,000	8,059,000	9,267,000	11,978,000	15,142,000
.001	3,819,000	9,605,000	12,430,000	12,995,000	17,967,000
.01	3,164,000	7,458,000	10,283,000	10,504,000	13,060,000
1	226,000	452,000	452,000	452,000	1,130,000
.2					226,000
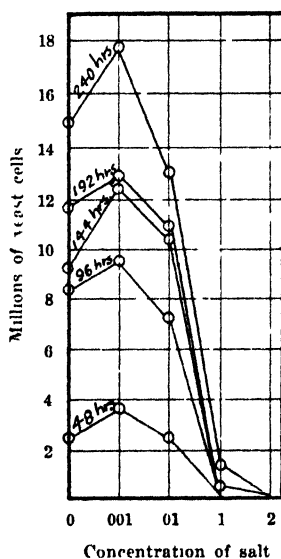
Fig. 4.—The ordinates represent the number of yeast cells in millions and the abscissae, the concentration of NaCl. The ordinate at 0 represents the number of yeast cells in blank cultures.

NaCl shows a directly opposite reaction with yeast from that found by Lipman[11] with soil bacteria. Both Loeb and Ostwald found NaCl to be toxic for animals, but less so than we have found with yeast. The toxicity of NaCl to animals may be compared with the toxicity of NaCl₂ to yeast. Loeb[3] found it impossible to develop embryos in the egg of *Fundulus* at .625M NaCl. Osterhout[8, 9] found that a .375M solution of sodium chloride is fairly toxic to marine plants. Young plants of a fresh-water alga, *Vaucheria sessilis*, could not live at a .094M concentration of sodium chloride, and even a concentration of .0001M NaCl was found to be toxic. Magowan has shown that sodium chloride is very toxic to wheat seedlings and down to .02M the root hairs did not grow at all. The relation of yeast to plants is thus to a certain extent shown by similar physiological behavior.

It may be noted here that the experiments with yeasts have been conducted on the same general principle followed by previous investigators with animals, plants, and bacteria. The number of yeast cells was taken as the measure of multiplication or activity and was determined by a microscopical count of each flask every forty-eight hours. It must be admitted that experimental errors may occur in counting, but as the numbers were taken from the average results of two sets of duplicates it does not interfere with the validity of the final result, as the range of variation between the results of these two sets of duplicates was only between 0 and 10 per cent calculated from the mean variation.

SERIES V— EFFECT OF THE TOXICITY OF SALTS ON THE MICROSCOPICAL APPEARANCE OF YEAST CELLS

It is generally known that all salts at certain concentrations are more or less toxic to living organisms. Yeast shows its physiological condition in relation to various salts in characteristic ways. It is evident from the above experiments that in this respect it occupies a place between the animal and the plant kingdoms. Although yeast grows normally in a physiologically balanced solution, for which grape juice answers in every way, the addition of a small amount of a favorable salt, as potassium chloride, may stimulate the growth a great deal. This is of some practical zalue to zymologists.

Yeast is affected very remarkably by the toxicity of salts at different concentrations. In the extreme concentrations it apparently

dissolves. This occurs in the cultures having 2.2M KCl, 1.2M, MgCl₂, .7M CaCl₂, and .2M NaCl respectively. At lower concentrations there is a degenerated condition, various shapes occurring, as shown in figure C. Such diseased cells show a heavy black membrane, especially in the case of CaCl₂ and NaCl, with transparent cell-illusions or black spots within the cells. Moreover, they vary in size. This variation in size occurs also with KCl and MgCl₂, but in these cases the yeast cells are larger than with CaCl₂ and NaCl. In all instances, as the concentration of salt increases beyond the favorable degree of concentration the cells become smaller and smaller until finally, in the extreme concentrations, they dissolve. Table 5 (*a. b, c, d*) and the curves in figure 5 (*a, b*) show the effect on the size of yeast cells in different salt solutions.

TABLE 5a—EFFECT OF KCl ON SIZE OF YEAST CELLS (*S. ellipsoideus*)

Concentration of salt (M.KCl)	Av. length and breadth of yeast cells in Mu.	Av volume yeast cells calculated from length and breadth
.00	4.7 × 4.6	77
.001	5.4 × 5.4	122
.01	6.7 × 6.7	232
.1	6.7 × 6.7	232
.2	6.7 × 6.7	232
.4	6.6 × 6.6	223 ·
.6	6.6 × 6.6	223
.8	5.8 × 5.8	151
1.0	5.8 × 5.8	151
1.2	5.8 × 5.8	151
1.4	5.8 × 5.8	151
1.6	4.9 × 4.9	91
1.8	4.9 × 4.9	91
2.0	3.3 × 3.3	28
2.2	3.3 × 3.3	28

TABLE 5b—EFFECT OF MgCl₂ ON SIZE OF YEAST CELLS (*S. ellipsoideus*)

Concentration of salt (M MgCl₂)	Av. length and breadth of yeast cells in Mu.	Av volume yeast cells calculated from length and breadth
.00	4.5 × 4.5	71
.001	5.1 × 5.1	103
.01	6.2 × 6.2	185
.1	6.2 × 6.2	185
.2	5.0 × 5.0	98
.4	5.1 × 5.1	103
.6	5.0 × 5.0	98
.8	4.9 × 4.9	91
1.0	4.4 × 4.4	66
1.2	3.3 × 3.3	28

TABLE 5c—EFFECT OF CACL₂ ON SIZE OF YEAST CELLS (*S. ellipsoideus*)

Concentration of salt (M.CaCl₂)	Av. length and breadth of yeast cells in Mu.	Av. volume of yeast cells calculated from length and breadth
.00	4.7 × 4.4	70
.001	4.6 × 4.6	75
.01	4.1 × 4.1	53
.1	3.3 × 3.3	28
.2	3.3 × 3.3	28
.3	2.8 × 2.8	17
.4	2.8 × 2.8	17
.5	2.8 × 2.8	17
.6	2.6 × 2.6	14
.7	2.6 × 2.6	14

TABLE 5d—EFFECT OF NACL ON SIZE OF YEAST CELLS (*S. ellipsoides*)

Concentration of salt (M NaCl)	Av length and breadth of yeast cells in Mu	Av volume of yeast cells calculated from length and breadth
.00	5.1 × 4.8	91
.001	5.0 × 4.4	75
.01	4.4 × 3.3	37
.1	4.1 × 3.3	34
.2	2.6 × 2.6	14
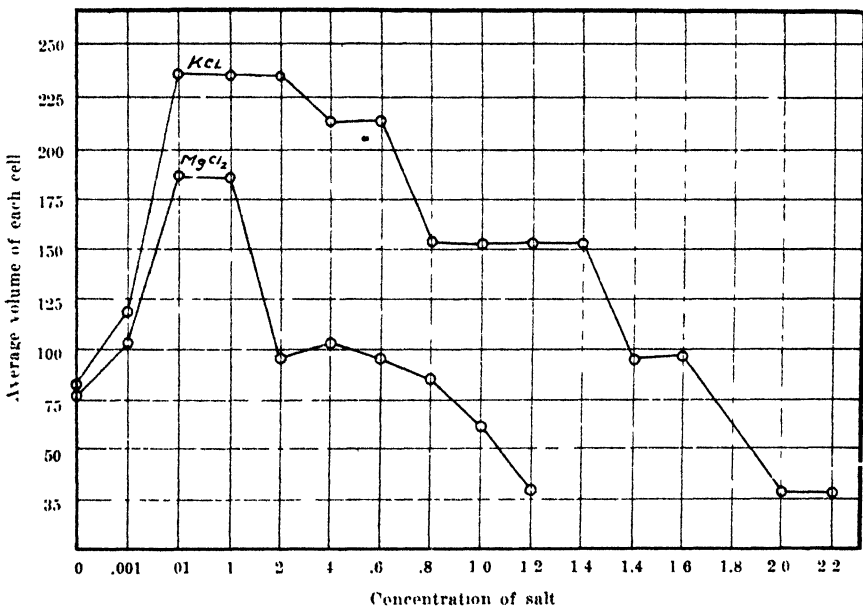
Fig. 5a.—Curves showing the average relative volumes of yeast cells in various concentrations of CaCl and MgCl₂. The ordinates represent the average volume of the yeast cells and the abscissae, the concentrations of KCl and MgCl₂ used. The ordinate at 0 represents the volume in blank cultures.
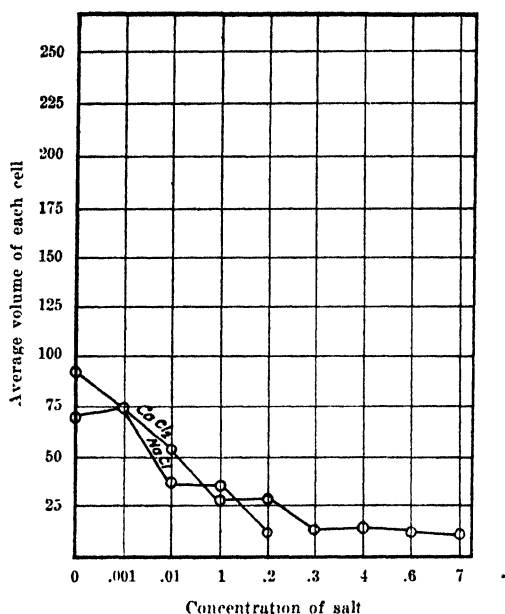
Fig. 5b.—Curves showing the average relative sizes in volumes of yeast cells in various concentrations of KCl and MgCl₂. The ordinates represent the volume of the yeast cells and the abscissae, the concentrations of the salts used. The ordinate at 0 represents the volume in blank cultures.
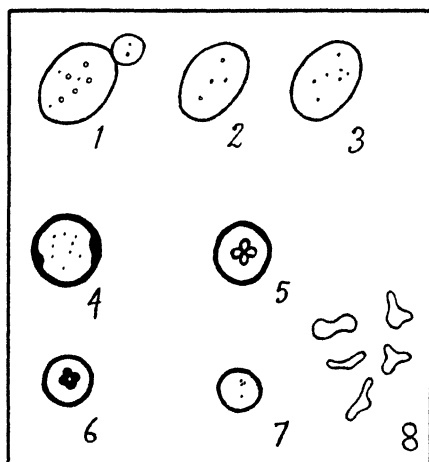
Fig. 5c.—Appearance of yeast cells in extreme concentrations of salts.

Normal yeast cells in 1, 2 and 3, diseased yeast cells from extreme concentrations of KCl and MgCl₂ in 4 and 5; (white) and diseased yeast cells from extreme concentrations of CaCl₂ and NaCl in 6, 7 and 8 (black or shadowy) (X5000).

The measurements given are the average of five counts in each case. The volumes from which the curves have been drawn in figure 5 (*a*, *b*) have been calculated, for purposes of comparison, as though the cells were cylindrical.

Both from table 5 (*a*, *b*, *c*, *d*) and the curves in figure 5 (*a*, *b*) it is evident that KCl and $MgCl_2$ favor growth in size up to the most favorable concentration, beyond which the cells decrease in size until the extreme concentration is reached, where they dissolve. Both NaCl and $CaCl_2$ limit the growth even in minute concentrations, thus showing their extreme toxicity to yeast cells.

Yeast cells seem to have remarkable resistant power. Many of them with cell wall thickened to a heavy membrane have been found in extreme concentrations. Perhaps this heavy membrane is formed to resist the osmotic pressure outside the cell. Besides some of the cells in these extreme concentrations are in normal condition and are even budding, thus showing the power of adaptability of yeast cells to new conditions. After they have become habituated to the presence of toxic salts, they grow normally and reproduce. It is probably owing to the adaptability of yeast to different conditions that the same yeast, *S. ellipsoideus*, collected from various sources, shows dissimilar physiological characters. Besides in many cases I have observed that the diseased yeast cells in extreme toxicity of KCl and $MgCl_2$ form a white membrane with normal cell contents, while those of $CaCl_2$ and NaCl form a rather dark cell membrane with shadowy cell contents. A similar case to that of Loeb[11] may be cited here. In his experiments with sea urchin eggs he found two distinct phases of cytolysis which he terms "black cytolysis" and "white cytolysis."

With regard to the effect of the salts on the size of the yeast cells, NaCl is the most and KCl the least toxic, while $CaCl_2$ and $MgCl_2$ stand midway. The effect is parallel with that of the multiplication of cells.

An experiment was carried on with a second culture of *S. ellipsoideus* collected from another source by Cruess and named no. 60. This experiment was also made in duplicate. With this yeast potassium chloride and magnesium chloride gave the same results as with no. 66, but NaCl and $CaCl_2$ showed a marked difference and $CaCl_2$ was the most toxic of all. 4M NaCl gave an appreciable number of yeast cells, while even .3M $CaCl_2$ stopped the growth altogether. Further, the number of yeast cells was much lower than that of yeast no. 66. Evidently yeast no. 60 was less vigorous than the other, though otherwise there was no fundamental difference between them.

B. Experiments With Combinations of Salts—Antagonistic Effects

The toxic effects of the single salts KCl, MgCl$_2$, CaCl$_2$ and NaCl upon a wine yeast, *S. ellipsoideus,* have been shown in the first part of this paper. The results of the study indicate that the reactions of yeast differ from those of plants, animals or bacteria. This second part of the paper gives the results of an investigation to ascertain the effects of various binary combinations of the salts named upon the same yeast.

From the four salts, six combinations of two salts each are possible. All of these were tested. Judging from analogous work of other investigators with animals, plants and bacteria, it was expected that these salts would exhibit mutually antagonistic action, i.e., that the toxicity of one salt would be reduced by the presence of another and that the total effect of two salts together would be less than the sum of their individual effects. In some cases definite antagonistic effects were found. In others antagonism was not so well defined. In a few instances there was no antagonism shown.

In the discussion of results, considerable space has been given to the findings of other investigators because it was considered important to point out how the effects on other organisms compare with those on yeast. A few words on the development of the idea of antagonism in binary combinations of salts will be of value as an introduction to the data in this paper.

Considerable work on the antagonistic effects of salts has been done by Ringer, Locke, Howell, Loeb, Osterhout, Overton, Ostwald, Loew, Lipman and others. That the poisonous effect of one salt is reduced by the addition of another salt has been known for a long time, especially among animal physiologists. In this matter we owe a great deal of our knowledge to Loeb, whose investigations brought forth a large number of unexpected results. It was he who first developed the theory that the valences of metallic ions have considerable influence on their toxic and antagonistic effects, and that monovalent cations may be antagonized by bivalent, trivalent or tetravalent but not by monovalent cations. His results show some parallelism to the work of Linder and Picton.* This general statement does not apply in all cases to plants, animals and bacteria, experimented upon by various other investigators. Neither does it apply always to yeast.

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* Hober and Gordon, Beitr. zur chem. physiol., vol. 5, p. 432, 1904, cited by Osterhout.^{22}

The experiments with binary salts were made in the same general way as those with simple salts, but with slight modifications of technique. The flasks were arranged as before in duplicate, but in combining the salts in different molecular concentrations the method followed differed from those of previous investigators.

Of the two salts to be tested for antagonism, one was weighed from the minimum concentration to that of extreme toxicity according to the molecular concentration, and the other was weighed and added to the former in the reverse way in the corresponding flasks. The flasks containing the extreme concentration of each salt did not receive any addition of the other salt. Aside from this, the methods of inoculation, incubation, and microscopical counting were the same as those described for the single salts. Duplicates were made in all cases and two blanks were used in each series, as checks on the growth of the yeast in the treated flasks. The same yeast, *S. ellipsoideus*, no. 66, was employed in these experiments as in the ones with simple salts. The results given are therefore the average of duplicate experiments.

SERIES VI—ANTAGONISM BETWEEN MAGNESIUM CHLORIDE AND CALCIUM CHLORIDE

In this series $MgCl_2$ and $CaCl_2$ were combined in various molecular concentrations. A series of 16 Erlenmyer flasks was arranged in duplicate with two blank cultures. First, amounts of $MgCl_2$ corresponding to from 0M to 2.2M were weighed and put in the flasks, as was done with the single salts. The $CaCl_2$ also was weighed according to its molecular concentration and put in the same flasks in reverse order, leaving the extreme concentrations of each salt free from the addition of the other. Thus the first two flasks received .72M $CaCl_2$ without any addition of $MgCl_2$; the second received .66M $CaCl_2$ and .001 $MgCl_2$; the third 60M $CaCl_2$ and .01M $MgCl_2$, and so on to the last couple, which contained only 1 2M $MgCl_2$ and no addition of $CaCl_2$. The remaining flasks were combined in different molecular concentrations, as shown in table 1. Two blanks were taken to which no salt was added.

In order to facilitate the plotting of the curves, the different combinations of salts have been indicated by letters A, B, C, D, etc. A represents the blank cultures, while the other letters represent the different molecular combinations shown in the table below:

TABLE 6—ANTAGONISTIC EFFECT BETWEEN MgCl₂ AND CaCl₂

No.	MgCl₂ vs. CaCl₂ M. Conc.		48 hrs.	96 hrs.	144 hrs.	192 hrs.	240 hrs.
A	.00	× .00	1,954,000	6,290,000	10,556,000	14,108,000	16,944,000
B	.00	× .72	....	....	....	....	....
C	.001	× .66	....	....	....	226,000	452,000
D	.01	× .60	452,000	2,034.000	3,842,000	4,520,000	5,650,000
E	.1	× .48	8,362,000	20,860,000	23,120,000	24,730,000	26,842,000
F	.2	× .36	10,848,000	26,024,000	29,706,000	30,856,000	31,960,000
G	.4	× .18	9,718,000	28,996,000	32,284,000	33,974,000	36,120,000
H	.6	× .06	8,804,000	25,286,000	30,256,000	31,865,000	32,556,000
I	.8	× .01	452,000	4,972,000	8,289,000	10,298,000	12,684,000
J	1.0	× .001	....	226,000	1,130,000	2,260,000	3,129,000
K	1.2	× .00	....	....	....	....	....
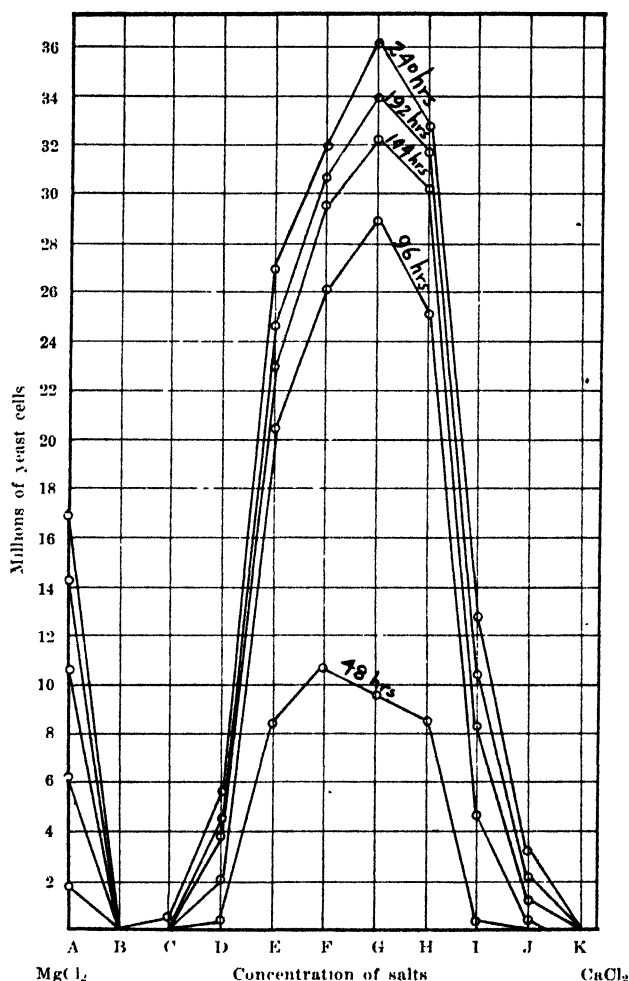
Fig. 6.—Curves of yeast growth showing antagonism between MgCl₂ and CaCl₂. The ordinates represent the number of yeast cells in millions and the abscissae, the concentration of the salts in combination. The ordinates at A represent the number of yeast cells in blank cultures.

From both table 6 and the curves in figure 6 it is evident that there is a distinct antagonism between these two salts. For example, in the experiments with simple salts $MgCl_2$ alone at .8M concentration allowed the growth of yeast cells up to only 8½ millions, but in combination with .01M $CaCl_2$ the growth was increased up to 12½ millions, i.e., 50 per cent increase. Similarly, .6M $CaCl_2$ alone allowed an increase to about one millions, and, with the addition of .01 $MgCl_2$, an increase to 5½ millions, showing 5½ times more growth. The highest number in $MgCl_2$ alone was 26½ millions at .1M, and in $CaCl_2$ alone 19 millions at .01M concentration. In this binary combination the highest number was obtained at G, the point where .4M $MgCl_2$ and .18M $CaCl_2$ were combined with a ratio of about 2:1.

For purposes of comparison let us now consider the results obtained in similar experiments with these four salts on plants, animals, and bacteria.

(a) *Plants.*—Kearney and Cameron[8] found a distinct antagonism between Mg and Ca ions for higher plants. In their experiments with leguminous plants *Lupinus albus* and *Medicago sativa* they found that, for a combination of these two salts, the plants show about five times as much tolerance as for the salts separately. The plants also displayed a remarkable degree of tolerance when $MgSO_4$ was used instead of $MgCl_2$, thus showing in addition the relative difference between different anions of the same salt.

Loew and his pupils,[10, 18] in their experiments with lower plants (*Spirogyra*), have found a strong antagonism between Mg and Ca ions.

(b) *Animals.*—Loeb[2] with sea urchins (blastulae and gastrulae) found that a mixture of $MgCl_2$ (10 8n) and $CaCl_2$ (10 8n) will allow them to swim for about forty-eight hours, while each of the salts singly at the same concentration is extremely poisonous and kills the animals. The same investigator[15] working with a jellyfish (*Polyorchis*) has shown that the addition of a small quantity of $CaCl_2$ to a mixture of $NaCl$ and $MgCl_2$ favors the normal, rhythmical contractions, while $MgCl_2$ alone stops them altogether. Contrary to the above results, Loeb[12] in his experiments with frogs has found that a combination of Mg and Ca ions completely inhibits the rhythmical muscular contractions. This has been corroborated by Anne Moore,[7] in her experiments with the contraction of the lymph hearts of frogs.

Lillie[9] has found that the ciliary movement of the larvae of

Arenicola goes on normally for a time in a mixture of $MgCl_2$ and $CaCl_2$ with the ratio of 4:1 at 10/8n concentration, though either of the two salts used alone would stop it entirely. Matthews,[11] in his work with the development of embryos in the eggs of *Fundulus,* found a distinct antagonism between Mg and Ca.

Meltzer and Auer[21] have shown with rabbits and a monkey that the poisonous action of $MgCl_2$ in subcutaneous injection is similarly diminished by the injection of $CaCl_2$. They found also a strong antagonism between the nitrates, acetates and sulfates of these two salts respectively.

(*c*) *Bacteria.*—Lipman,[23, 24] with a soil bacterium, *Bacillus subtilis,* found little or no antagonism between the two salts, but, on the contrary, the addition of one salt to the other was found to be more toxic than either of the two salts used alone.

All of the above mentioned experiments, except those of the three cases of Lipman, Loeb, and Anne Moore, are in agreement with the antagonistic effects between Mg and Ca ions that occur with yeast. In addition, it may be noted here that the antagonistic effect between $MgCl_2$ and $CaCl_2$ with yeast has been found to be the strongest of all the combinations. This corroborates the opinion advanced by Loew that there is a strong antagonism between calcium and magnesium both with plants and animals.[10]

SERIES VII—ANTAGONISM BETWEEN POTASSIUM CHLORIDE AND CALCIUM CHLORIDE

In this series the experiments were carried on in the same way as with $MgCl_2$ and $CaCl_2$. Table 7 and the curves in figure 7 show there is a distinct antagonism between the two salts. In this case marked antagonism was found on the side of $CaCl_2$, but little or none on the side of KCl. For example, the combination of .001M KCl with .66M $CaCl_2$ allowed the yeast to grow up to $6\frac{1}{2}$ millions, while in $CaCl_2$ at .6 alone the yeast was found to increase only up to about one million. Thus there was $6\frac{1}{2}$ times as much growth where the KCl was present. But, on the other hand, the combination of .001M $CaCl_2$ to 2 0M KCl did not accelerate the growth. This unexpected result may be accounted for by the fact that the higher concentrations of KCl being very high in comparison to the small concentrations of $CaCl_2$ the latter was not sufficient to reduce the toxicity of the KCl at such a high concentration. It is also very probable that a concen-

tration of 2.0M KCl exerts a strong osmotic effect and that the toxicity is due to osmotic influences rather than to the usual toxicity of the ion itself. If this were true we would expect little antagonism from other salts.

Loeb[12] in his experiments with a jellyfish (*Gonionemus*) met with a similar difficulty. In this case the KCl concentration was so high that a small concentration of NaCl did not remove the toxicity, and so the combination inhibited the contraction of the animal, while the same concentrations used in the case of another kind of fish, *Fundulus*, allowed the development of embryos in the eggs. He has pointed out the fact that in the embryos of *Fundulus* the solutions in which cleavage proceeds normally interferes seriously with the heartbeat of *Gonionemus*, if the proportion of KCl exceeds a certain limit. In this instance we find proof of the fact that in the same organism cell-division and muscular contractility are influenced by entirely different combinations of ions, and therefore these vital activities must depend on widely different chemical constitutions. However, the highest growth in the case of yeast was obtained at H, where .6M KCl and .36M CaCl₂ have been combined, a ratio of about 2:1. In the case of KCl alone the highest growth was obtained at .2M concentration, allowing growth up to 30½ millions per c.c. CaCl₂ allowed growth up to 19 millions at .01M concentration.

TABLE 7—ANTAGONISTIC EFFECTS BETWEEN KCl AND CaCl₂

No	KCl vs CaCl₂ M Conc		48 hrs	96 hrs	144 hrs	192 hrs	240 hrs
A	.00	× .00	2,101,000	8,589,000	13,908,000	16,896,000	17,520,000
B	00	× .72					
C	.001	.66		226,000	2,034,000	3,985,000	6,722,000
D	01	× .60	452,000	4,972,000	13,315,000	18,604,000	22,720,000
E	1	× 54	4,020,000	10,328,000	20,245,000	23,266,000	25,120,000
F	2	× 48	5,558,000	12,840,000	22,190,000	26,880,000	29,380,000
G	.4	× 42	3,034,000	12,840,000	26,852,000	19,126,000	32,285,000
H	.6	× 36	1,017,000	8,398,000	13,645,000	28,904,000	34,500,000
I	.8	× .30	226,000	4,256,000	10,250,000	14,966,000	18,732,000
J	1.0	× .24		2,965,000	6,126,000	9,551,000	16,159,000
K	1.2	× .18		1,130,000	3,986,000	5,410,000	7,119,000
L	1.4	× .12		452,000	2,550,000	2,712,000	4,438,000
M	1.6	× .06			904,000	1,130,000	3,906,000
N	1.8	× .01			452,000	904,000	2,652,000
O	2.0	× .001				226,000	1,130,000
P	2.2	× .00					
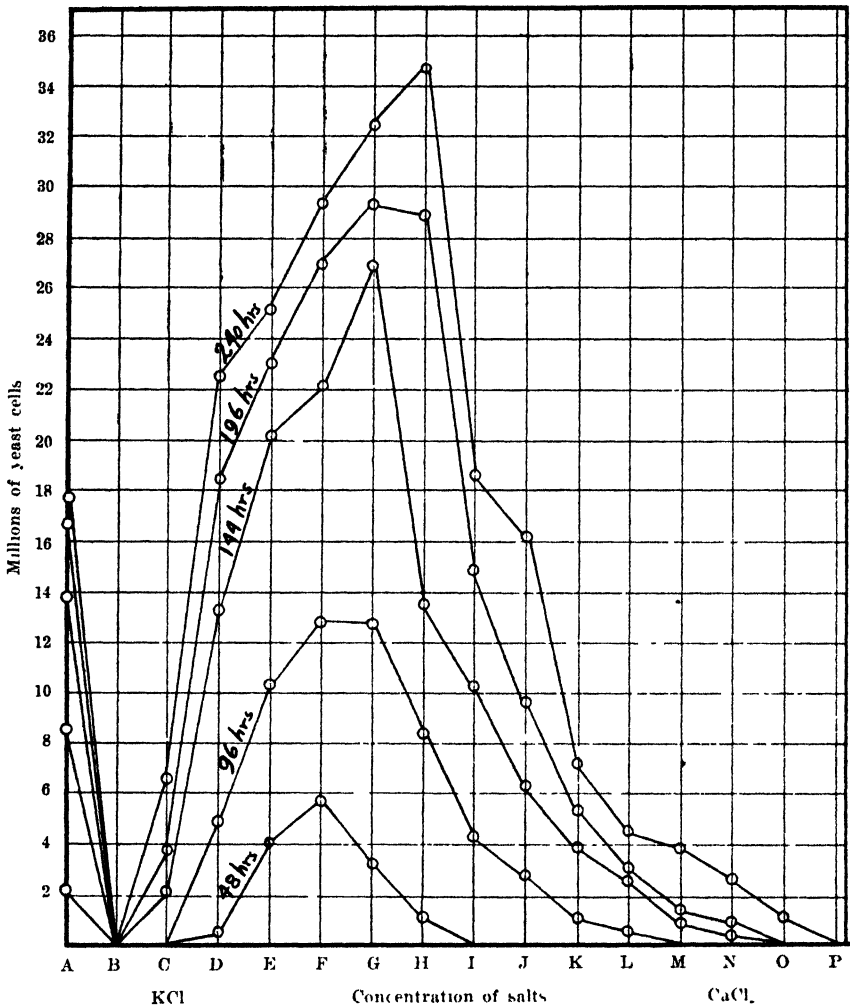
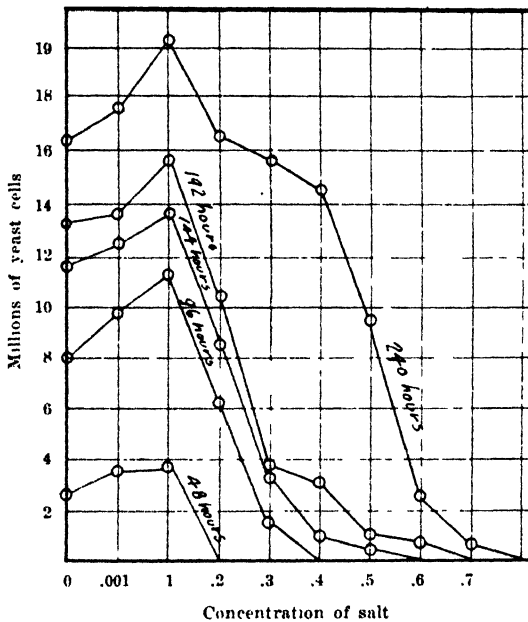Fig. 7.—Curves of yeast growth showing antagonism between KCl and CaCl₂. The ordinates represent the number of yeast cells in millions and the abscissae, the concentration of salts in combination. The ordinate at A represents the number of yeast cells in blank cultures.

For comparison with these results, a number of cases dealing with plants, animals and bacteria may be cited below:

(a) *Plants.*—Osterhout[22] has shown that for higher plants a combination of 100 c.c. KCl and 5 c.c. CaCl₂ at the concentration of .12M is best suited for the highest development of roots. Benecke[19] has shown that for lower plants (*Spirogyra*) the harmful effect of the K ion is very distinctly antagonized by the addition of the Ca ion at a certain definite concentration.

(*b*) *Animals.*—In regard to the development of embryos in the eggs of *Fundulus,* Loeb[1] has met with a marked antagonism between the two salts, using 75 c.c. of KCl (5/8n) and 25 c.c. of $CaCl_2$ (10/8n). This combination allowed the development of a number of embryos, while in the same concentration of KCl alone no development was shown. He also obtained a similar result with the muscular contraction of a jellyfish (*Polyorchis*),[15] thus showing an antagonistic effect between the two salts. The same investigator[3] in his experiments with the hydromedusa *Gonionemus* has shown that the combination of K ion (5/8n) and Ca ion (10/8n) is poisonous to the animals. Anne Moore[7] obtained a similar result in her experiments on the contraction of the lymph heart of frogs.

Meltzer and Auer[21] have shown that with rabbits and a monkey in subcutaneous injection there is a limited antagonism between the two salts. Matthews[11] with *Fundulus* met with a similar result. He found that at the dilution of M/1600 $CaCl_2$ to 6 8n KCl the development of embryos in the eggs was found to be the best.

Lillie[6] found that with the larvae of *Arenicola* the ciliary activity went on when he used 97.5 c.c. $CaCl_2$ (10 8n) and 2.5 c.c. KCl (5 8n), showing an antagonism between the two salts.

(*c*) *Bacteria.*—Lipman[23] has shown that for *Bacillus subtilis* the highest production of ammonia is found at the point where 100 c.c. KCl and 5 c.c. $CaCl_2$ at the concentration of .35M is used, thus showing a distinct antagonism between the two salts. His work has a striking similarity to that of Osterhout on wheat.

Summarizing the antagonism between K and Ca, it may be said that the toxicity of high concentrations of Ca is greatly reduced by the presence of K, but that the toxicity of high concentrations of K is not appreciably reduced by small amounts of Ca. The optimum ratio of KCl to $CaCl_2$ was about 2:1 for yeast.

SERIES VIII - ANTAGONISM BETWEEN MAGNESIUM CHLORIDE AND SODIUM CHLORIDE

The experiments in this series were carried on in the same way as the others. Both table 8 and the curves in figure 8 show that there is a distinct antagonism between these two salts. The highest growth in this case was found at G, the point where .4M $MgCl_2$ and .06M NaCl were combined, a ratio of about 6:1. As already shown, when used singly $MgCl_2$ allows the highest growth at .1M, i.e., $26\frac{1}{2}$ millions,

TABLE 8—ANTAGONISTIC EFFECTS BETWEEN MgCl₂ AND NaCl

No.	MgCl₂ vs. NaCl	M Conc	48 hrs.	96 hrs.	144 hrs.	192 hrs.	240 hrs.
A	.00	×.00	3,100,000	7,644,000	13,686,000	15,203,000	17,009,000
B	.00	×.208	....	.. ..	... .	. .	..
C	.001	×.180	....	.. . .	....	226,000	226,000
D	.01	×.160	226,000	452,000	452,000	678,000	1,130,000
E	.1	×.128	3,250,000	6,212,000	11,201,000	14,258,000	17,255,000
F	.2	×.096	5,424,000	10,396,000	16,368,000	21,690,000	25,793,000
G	.4	×.064	2,260,000	12,656,000	20,696,000	25,882,000	28,890,000
H	.6	×.032	1,582,000	8,684,000	14,956,000	17,009,000	21,583,000
I	.8	×.01	904,000	3,102,000	6,358,000	10,605,000	15,430,000
J	1.0	×.001	... .	904,000	1,872,000	3,896,000	4,276,000
K	1.2	×.00		... ..	.	. . .	
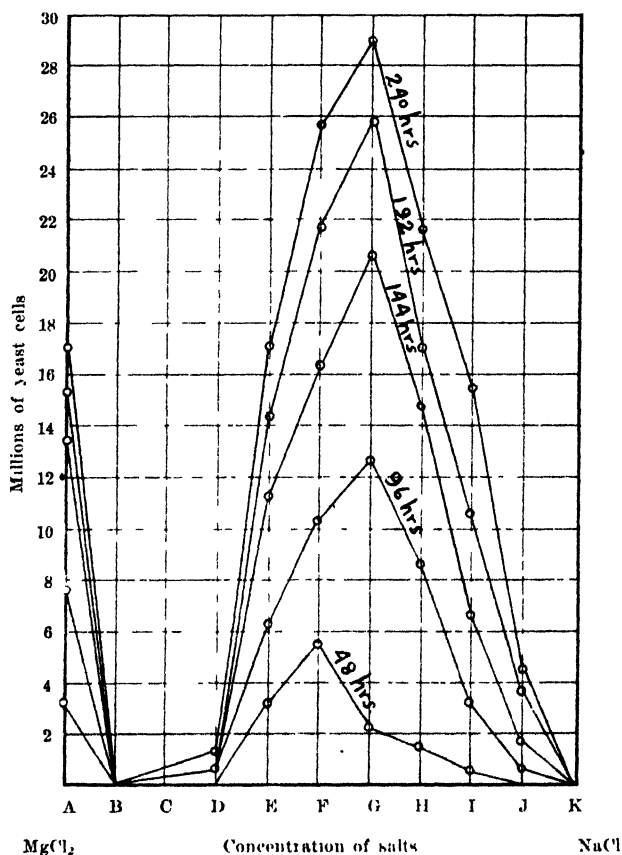
Fig. 8.—Curves of yeast growth showing antagonism between MgCl₂ and NaCl. The ordinates represent the number of yeast cells in millions and the abscissae, the concentration of salts in combination. The ordinate at A represents the number of yeast cells in blank cultures.

and NaCl at .001M, i.e., 18 millions. But in combination the two salts permit the highest growth of 29 millions per c.c. at .4M and .06M respectively.

The antagonism between these two salts in the case of yeast is found very distinctly at both ends of the curves. For example, .1M NaCl alone shows a growth of scarcely more than one million, while in combination with .1M MgCl$_2$ it shows over 17 millions, or 17 times as much. On the other hand, .8M MgCl$_2$ alone allowed a growth of about 8½ millions, while in combination with .01M NaCl the growth was increased to about 15½ millions, or about twice as much.

In comparison with these results, a number of cases dealing with the effects of combinations of MgCl$_2$ and NaCl on plants, animals and bacteria are cited below.

(a) *Plants.*—Osterhout[5] found a distinct antagonism between the two salts with the growth of a fungus (*Botrytis cinerea*). He found that 15.M NaCl alone was very toxic, but that when this concentration of NaCl was combined with .4 M MgCl$_2$ the toxicity was much reduced. He also found with wheat that neither NaCl nor MgCl$_2$ at .12M alone allowed root development, but in a combination in the proportion of 100 c.c. NaCl to 75 c.c. MgCl$_2$ the root developed very well. The same investigator obtained a negative result with green algae.[20]

Kearney and Cameron[4] with *Lupinus albus* and *Medicago sativa* have shown that the addition of MgCl$_2$ to NaCl raised the tolerance of these plants to the latter 3–10 times.

(b) *Animals.*—Loeb[12] with *Fundulus* has found that in a mixture of 98 c.c. 5 8n NaCl and 2 c.c. 10 8n MgCl$_2$ all the eggs develop embryos, while the same salts alone at the same concentration are extremely toxic. Even an equal proportion of the two salts in the same concentration allowed about 75 per cent of the embryos to develop. He also found a similar antagonism with a sea urchin (*Arbacia*) and a jellyfish (*Polyorchis*).

Lillie[6] found that with the larvae of *Arenicola* the ciliary movement continued for a time when he added 10 c.c. MgCl$_2$ (10 8n) to 90 c.c. NaCl (5 8n), while the same concentrations of NaCl alone would stop it immediately. Matthews with *Fundulus* found an antagonism between the two salts.

Ostwald,[13] however, with fresh-water *Grammarus* obtained contrary results. In this case a combination of the two salts was found

to be more toxic than NaCl alone, isotonic with sea water (2.7 per cent NaCl in sea water or about .4M NaCl).

(*c*) *Bacteria.*—Lipman[23] with *Bacillus subtilis* obtained a result similar to that of Osterhout. A mixture of the same concentration of MgCl$_2$ and NaCl (.35M) in the ratios of 10:1 gave the maximum production of ammonia.

To summarize the results of these experiments, it may be said that there is a distinct antagonism between MgCl$_2$ and NaCl, which is evident on both ends of the curves in figure 8. In this case the yeast agrees with the observations on plants, animals and bacteria except in the two instances cited above in regard to fresh-water *Grammarus* and green algae.

SERIES IX—ANTAGONISM BETWEEN POTASSIUM CHLORIDE AND SODIUM CHLORIDE

In this series the flasks were arranged as before. It has been pointed out by Loeb that two salts with ions of like valence, especially in the case of monovalent ions, do not antagonize the toxicity of each other, but rather show a moderately increased toxicity when combined. This is evident with yeast, as is shown by table 9 and the curves in figure 9. The highest growth in this case was found at F, where .2M KCl and .12M NaCl have been combined, having a ratio of about 2:1. KCl alone at .2M concentration allows the growth about 1½ times that found in this combination. Thus the antagonism of NaCl for KCl is found to be negative. But, on the other hand, there is a distinct antagonism of KCl for NaCl. For example, NaCl alone at .17M concentration hardly allowed any growth, but in combination with .01M KCl the growth was accelerated up to about 15 millions, thus showing a distinct antagonism. The reason of this unexpected negative result on the side of KCl is perhaps the same that I have suggested in the case of KCl and CaCl$_2$ in Series II.

For comparison with these results, a number of cases dealing with plants, animals and bacteria are cited below:

(*a*) *Plants.*—Osterhout[22] with wheat (Early Genésee) has found a slight antagonism between K and Na ions. But in his work[17] on a green alga he obtained a negative result using 3/8M concentration of two salts in combination.

(*b*) *Animals.*—Loeb[1] with *Fundulus* found a slight antagonism between the K and the Na ion in relation to the development of em-

TABLE 9—ANTAGONISTIC EFFECTS BETWEEN KCL AND NACL

No	KCl vs NaCl	M Conc	48 hrs	96 hrs	144 hrs	192 hrs	240 hrs
A	.00	× .00	1,954,000	6,290,000	10,556,000	14,108,000	16,944,000
B	.00	× .208					
C	.001	× .192		226,000	1,808,000	6,780,000	7,888,000
D	.01	× .176	2,678,000	7,184,000	9,256,000	12.176,000	14,952,000
E	.1	× .160	5,424,000	10,786,000	14,690,000	16,922,000	18,566,000
F	.2	× 144	2,938,000	12,339,000	15,942,000	18,206,000	21,250,000
G	.4	× .128	2,260,000	7,838,000	11,526,000	15,830,000	17,248,000
H	.6	× .112	678,000	6,780,000	8,678,000	12,687,000	13,266,000
I	.8	× 096	226,000	5,650,000	7,205,000	10,256,000	12,984,000
J	1 0	× 080		4,156,000	5,882,000	8,120,000	9,886,000
K	1.2	× .064		2,906,000	4,900,000	7,750,000	8,205,000
L	1 4	× .048		1,130,000	3,390,000	4,968,000	6,983,000
M	1.6	× 032		452,000	1,130,000	2,260,000	4,452,000
N	1 8	× 010			226,000	1,130,000	2,960,000
O	2 0	× 001				452,000	904,000
P	2 2	× 00					
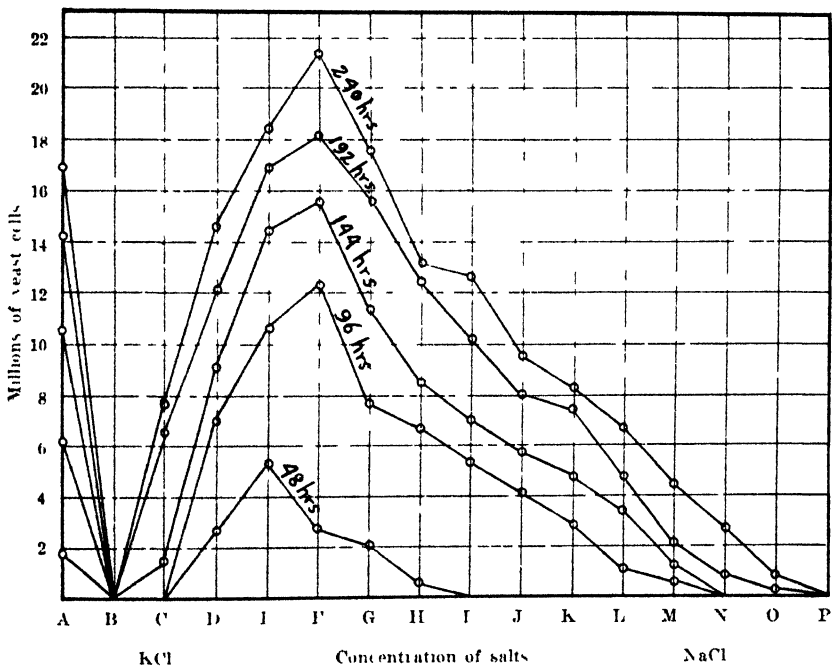
Fig. 9.—Curves of yeast growth showing antagonism between KCl and Nacl. The ordinates represent the number of yeast cells in millions and the abscissae, the concentration of salts in combination. The ordinate at A represents the number of cells in blank cultures.

bryos in the eggs. He also found a similar result with sea-urchins, *Hydromedusa gonionemus*, and a jellyfish, *Polyorchis*.

Lillie[6] found that with the larvae of *Arenicola* the ciliary movement goes on in a solution containing 20 parts of NaCl (5/8n) and 8 parts of KCl (5/8n), while each salt used alone stops the movement altogether.

Ostwald[13] with fresh-water *Gammarus* has shown that there is a distinct antagonism between K and Na ions in regard to the duration of life of that animal. Matthews[11] has found that it takes twice as much KCl to neutralize the toxicity of NaCl in the case of the development of embryos in the eggs of *Fundulus*. This is rather similar to the case of yeast, where it takes .2M KCl to neutralize the toxicity of .14M NaCl to allow the highest growth.

(*c*) *Bacteria.*—Lipman[23] with *Bacillus subtilis* has found that none of the combinations of these two salts gives as favorable conditions for growth as is found with each salt alone at the same concentration, thus showing non-antagonism between the two salts.

To summarize the results in this experiment, it may. be said that with yeast, like valences prevent the antagonistic effects, contrary to what was found by Lipman with soil bacteria, but in accordance with the results of Osterhout with wheat, Loeb with *Fundulus*, and other investigators with other organisms. The yeast agrees in this case with all the above-mentioned cases except with that of green algae tested by Osterhout and that of *Bacillus subtilis* by Lipman.

SERIES X—ANTAGONISM BETWEEN POTASSIUM CHLORIDE AND
MAGNESIUM CHLORIDE

The experiments in this series were conducted like the others. The highest growth in this case was found at II, the point where .6M KCl and .5M MgCl₂ were combined in a ratio of about 1:1. In the case of simple salts KCl alone at .2M concentration allowed the highest growth up to about 30½ millions and MgCl₂ at .1M about 26½ millions. KCl alone at .6M and MgCl₂ at .5M permitted the growth of yeast more than is found in this combination at H. But this indicates a mild antagonism, because the toxic effect was less than the sum of the separate toxic effects of the two salts used alone. Distinct antagonism to the effects of MgCl₂ is shown by KCl, but not the converse. For example, .8M MgCl₂ alone allows the yeast to grow only to 8 millions, while in the combination with .1M KCl the growth has

been increased to 11½ millions. On the other hand, the smaller concentrations of $MgCl_2$ with higher concentrations of KCl did not show any antagonism. The reason for this unexpected result is perhaps that previously mentioned in the case of KCl vs. $CaCl_2$ in Series VII.

TABLE 10—ANTAGONISTIC EFFECTS BETWEEN KCL AND MgCL

| No	KCl vs MgCl₂ M Conc	48 hrs	96 hrs	144 hrs	192 hrs	240 hrs
A	.00 × .00	2,356,000	9,701,000	12,170,000	14,890,000	17,526,000
B	.00 × 1.2					
C	.001 × 1.0		226,000	1,130,000	2,260,000	3,845,000
D	.01 × .9	226,000	1,356,000	6,780,000	10,070,000	11,560,000
E	.1 × .8	1,130,000	6,780,000	7,408,000	10,975,000	12,180,000
F	.2 × .7	1,356,000	7,458,000	11,578,000	13,449,000	14,328,000
G	.4 × .6	2,486,000	4,838,000	7,006,000	14,690,000	15,500,000
H	.6 × 5	904,000	3,816,000	5,296,000	12,550,000	16,280,000
I	.8 × .4	678,000	2,612,000	4,852,000	8,286,000	9,856,000
J	1 0 × .3	452,000	2,260,000	3,706,000	5,463,000	5,902,000
K	1.2 × .2	452,000	2,040,000	3,295,000	4,895,000	5,240,000
L	1 4 × 1	678,000	1,926,000	2,940,000	3,656,000	4,864,000
M	1.6 × .05	226,000	904,000	3,050,000	3,006,000	4,628,000
N	1.8 × .01		226,000	2,260,000	2,990,000	3,862,000
O	2.0 × .001				2,226,000	1,130,000
P	2 2 × 00					
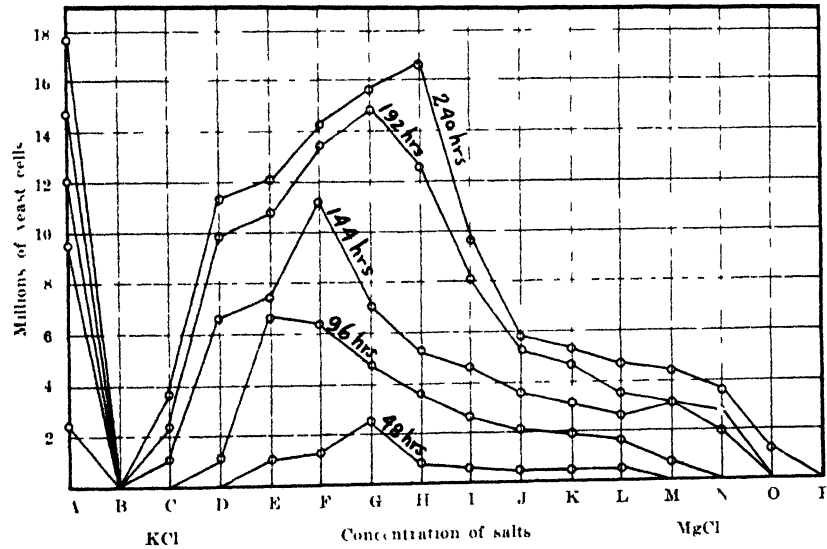
Fig. 10.—Curves of yeast growth showing antagonism between KCl and $MgCl_2$. The ordinates represent the number of yeast cells in millions and the abscissae, the concentration of salts in combination. The ordinate at A represents the number of cells in blank cultures.

For comparison with these results. a few cases may be cited as follows:

(*a*) *Plants.*—Osterhout[20] with wheat (Early Genésee) has shown that the root develops better in a solution having 100 c.c. KCl and 7.5 c.c. MgCl$_2$ at .12M concentration than in KCl alone. He also found with a marine alga,[20] *Enteromorpha hopkirkii*, that both salts are poisonous when used alone, but a combination in the proportion of 100 c.c. MgCl$_2$ and 40 c.c. KCl allows considerable growth. He found a similar antagonism with liverworts.[20]

(*b*) *Animals.*—Matthews[11] found with *Fundulus* that in order to permit development of the embryos in the eggs at the concentration of 33/48n KCl at least about M/160 MgCl$_2$ is needed. He also found that a solution of 6/8n KCl requires M/80 MgCl$_2$ to give the best result.

(*c*) *Bacteria.*—Lillie[6] has shown that a combination of 10/8n MgCl$_2$ and 5/8n KCl allows the ciliary activity of the larvae of *Arenicola*, which is stopped when one salt is used alone.

To summarize, it may be said that a distinct antagonism was found by Osterhout with higher and lower plants and by Matthews and Lillie with animals. With yeast a slight antagonism is found, which is shown on the curves in figure 10 on the side of MgCl$_2$.

SERIES XI—ANTAGONISM BETWEEN CALCIUM CHLORIDE AND SODIUM CHLORIDE

The plan of this series of experiments was the same of that of the others. In the case of simple salts both CaCl$_2$ and NaCl were found to be very toxic, and it may be owing to this extreme toxicity that the combinations of the two salts showed increased toxicity. Both from table 11 and the curves in figure 11 it is evident that this toxicity is very marked. The highest growth was found at E, where .1M CaCl$_2$ and .12M NaCl have been combined in the ratio of 1:1. But even here the number of yeast cells went up only to 8 millions, which is far below the highest growth obtained when the salts were used alone. However, CaCl$_2$ shows slight antagonism to the toxicity of NaCl, for example, .1M NaCl$_2$ alone allows the growth only to one million, while in combination with .1M CaCl it reached more than 8 millions. On the whole, however, both from the table and the curves it is evident that the combinations of the two salts are more toxic than the single salts.

TABLE 11—ANTAGONISTIC EFFECTS BETWEEN $CaCl_2$ AND NACL

No.	NaCl	CaCl₂ vs. M. Conc	48 hrs.	96 hrs.	144 hrs.	192 hrs.	240 hrs.
A	.00	× .00	2,356,000	9,381,000	12,172,000	14,890,000	17,108,000
B	.00	× .208	....	....			....
C	.001	× .18	226,000	226,000	226,000	904,000	1,130,000
D	.01	× .16	226,000	1,582,000	3,390,000	4,682,000	5,842,000
E	.1	× .12	226,000	1,808,000	5,650,000	7,910,000	8,290,000
F	.2	× .09	....	1,356,000	3,482,000	4,520,000	7,042,000
G	.3	× .06	....	226,000	1,130,000	5,650,000	6,820,000
H	.4	× .03	. . . .	.. . .	226,000	3,390,000	4,526,000
I	.5	× .01	.. ....	.. ..	... .	....	452,000
J	.6	× .001	. ... ---	....	....	....	....
K	.7	× .00	. . . . .	....	....	....	....
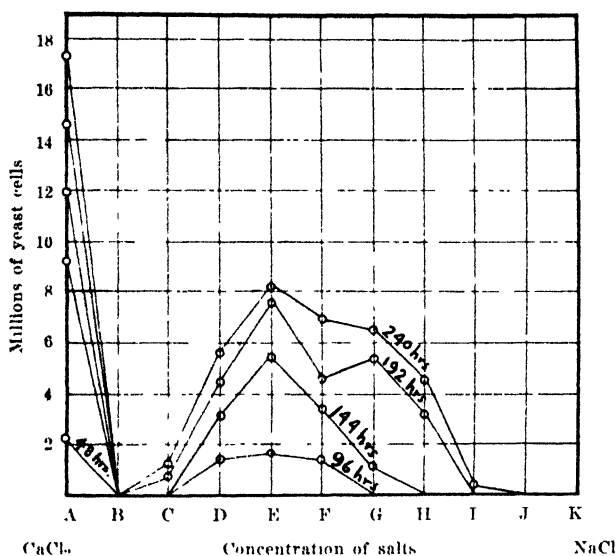
Fig. 11.—Curves of yeast growth showing effects of NaCl on $CaCl_2$. The ordinates represent the number of yeast cells in millions and the abscissae, the concentration of salts in combination. The ordinate at A represents the number of yeast cells in blank cultures.

For comparison with other organisms the following cases are cited:

(a) *Plants.*—Osterhout[5] with wheat found a distinct antagonism between the two salts. He obtained a similar result with green algae in which he used 100 c.c. NaCl and 10 c.c. $CaCl_2$ at the concentration of 3/8M. Kearney and Cameron,[8] with leguminous plants, found that a combination of the two salts increased the tolerance of the plants for $CaCl_2$ three times.

(*b*) *Animals.*—Loeb[1] with *Hydromedusa Gonionemus* has shown that a combination of 10/8n $CaCl_2$ and 5/8n NaCl is harmless to animals. He[15] also found a distinct antagonism with a jellyfish, *Polyorchis,* using 50 c.c. NaCl and 1 c.c. $CaCl_2$, which allowed the animal to swim, while NaCl alone was poisonous. The same investigator found a distinct antagonism between these two salts working with the development of embryos in the eggs of the *Fundulus.* Anne Moore[7] with the contraction of the lymph heart of frogs and Lingle[4] with that of the turtle's heart noted similar phenomena, thus corroborating the work of Loeb.

Lillie[6] working with the larvae of *Arenicola* has found a distinct antagonism between Ca and Na ions. MacCallum[14] found the same with his experiments on cathartics.   .

Meltzer and Auer[21] found a distinctly antagonistic effect with animals in subcutaneous injections. Ostwald[11] wth fresh-water *Grammarus* found a strong antagonism between NaCl and $CaCl_2$ in regard to the duration of life of that animal. Finally, Matthews[11] has shown that there is a slight antagonism between the two salts in the development of embryos in the eggs of *Fundulus.*

(*c*) *Bacteria.*—Lipman[24] with *Bacillus subtilis* found a marked lack of antagonism between the two salts. In his case any combination of the two salts at .35M concentration was found to be more poisonous than a single salt.   '

All these experiments except that of Lipman show that there is antagonism between $CaCl_2$ and NaCl. The yeast agrees very markedly with *Bacillus subtilis* in showing little or no antagonism between the two salts, $CaCl_2$ and $NaCl_2$.

RELATIVE ANTAGONISMS OF VARIOUS COMBINATIONS

Table 12 is intended to show the relative antagonisms of the various combinations. The data used in constructing the table are the final counts in each flask.

The average of the counts in all the check flasks is taken as the basis from which to estimate the influence of the various salts and of their combinations. The calculation is made as follows:

Yeast growth in check flasks = 17 (millions).
Yeast growth with single salt no. 1 = a.
Yeast growth with single salt no. 2 = b.
Yeast growth with combination no. $1 + 2 = c$.
Toxicity — expected $= (17 - a) + (17 - b)$.
Toxicity — observed $= 17 - c$.
Antagonism of combinations* $= (17 - a) + (17 - b) - (17 - c)$.
$\therefore$ Antagonism $= 17 + c - a - b$.

TABLE 12—RANGE OF ANTAGONISM OF THE BINARY COMBINATIONS CALCULATED FROM THE LAST MICROSCOPICAL COUNT*

No	$MgCl_2 \times CaCl_2$	$KCl \times CaCl_2$	$MgCl_2 \times NaCl$	$KCl \times NaCl$	$KCl \times MgCl_2$	$CaCl_2 \times NaCl$
A†	17,000,000	17,000,000	17,000,000	17,000,000	17,000,000	17,000,000
B						
C		4,000,000		5,000,000	1,000,000	
D	4,000,000	17,000,000		8,000,000	10,000,000	4,000,000
E	27,000,000	17,000,000	8,000,000	9,000,000	9,000,000	7,000,000
F	24,000,000	18,000,000	25,000,000	8,000,000	7,000,000	7,000,000
G	20,000,000	30,000,000	27,000,000	7,000,000	16,000,000	6,000,000
H	21,000,000	31,000,000	14,000,000	7,000,000	9,000,000	
I	7,000,000	5,000,000	11,000,000	10,000,000		
J	1,000,000	1,000,000	2,000,000	10,000,000	-	
K				1,000,000		
L						
M						
N						
O						
P						

† Millions on average
* These results are shown graphically by the curves in figure 12

* This defines 'antagonism' as the difference between the expected and the observed toxicity.

The curves have been drawn to show the antagonism of the combinations and not the actual growth of the yeast as has been shown in the previous curves.
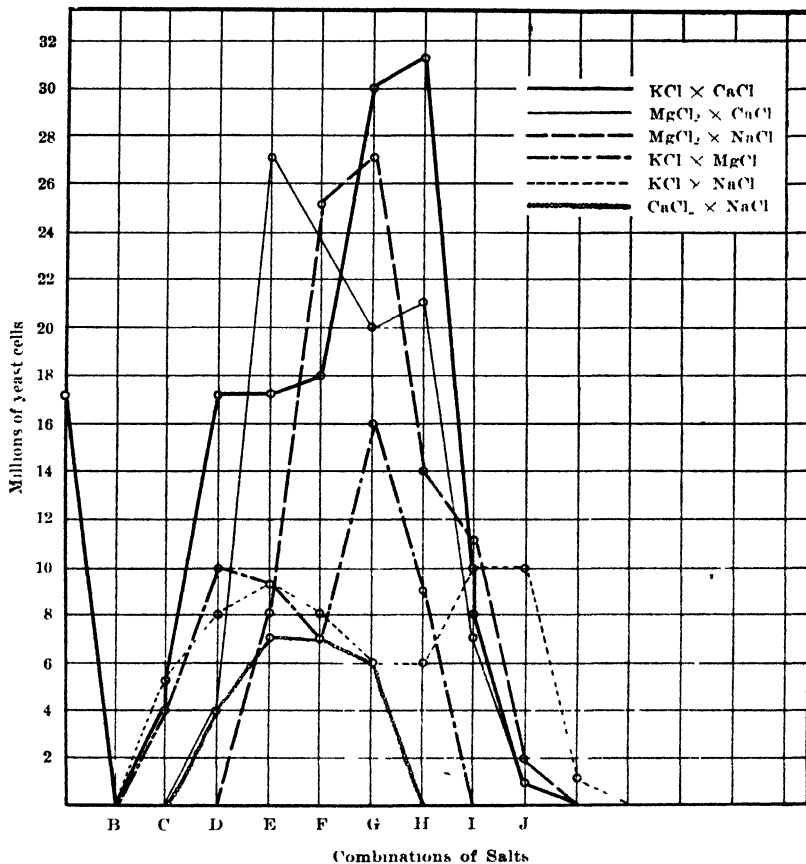
Fig. 12.—Curves showing range of antagonism of binary combinations of salts. The ordinates represent the average number of yeast cells in millions and the abscissae, the concentration of salts in combinations. The ordinate at A represents the average number of cells in blank cultures.

SUMMARY

PART A--TOXIC EFFECTS OF SINGLE SALTS

1. Each of the four single salts—KCl, $MgCl_2$, $CaCl_2$, and NaCl—is more or less toxic to the yeast, *Saccharomyces ellipsoideus*, at certain concentration. KCl is the least toxic and NaCl the most for the yeast (no. 66) used.

2. The lower concentrations of each salt stimulate the growth of yeast. The highest number of yeast cells in microscopical count was found at .2M KCl, .1M $MgCl_2$, .01M $CaCl_2$, and .001M NaCl, KCl being the most favorable and NaCl the least. Beyond the favorable concentrations the various salts are toxic to yeast.

3. The concentrations of salts that inhibited the growth of yeast cells were found at 2.2M KCl, 1.2M $MgCl_2$, .7M $CaCl_2$, and .2M NaCl.

4. The results of the experiments are quite different from those found with either bacteria, the higher plants or animals. The yeast stands in this respect midway between plants and animals and swings to either direction according to the environment.

5. The salts used had a marked effect on the size and appearance of the yeast. Taking decrease in size as a criterion, the salts affected the yeast toxically in the same relative ways as indicated by the rate of multiplication of the cells.

PART B—ANTAGONISTIC EFFECTS OF COMBINATIONS OF SALTS

1. As shown by growth of yeast, the variation in antagonism between the four single salts in all possible combinations may be arranged in order as follows:

1. $MgCl_2$ vs. $CaCl_2$ (most)
2. KCl vs. $CaCl_2$
3. $MgCl_2$ vs. NaCl
4. KCl vs. NaCl
5. KCl vs. $MgCl_2$
6. $CaCl_2$ vs. NaCl (least)

2. The effect of binary salts with yeast, whether positively or negatively antagonistic in comparison to animals, plants and soil bacteria, may be tabulated as follows:

Binary salts	Yeast	Animals	Plants	Soil bacteria
1. MgCl$_2$ vs. CaCl$_2$	+	+ and −	+	—
2. KCl vs. CaCl$_2$	+ and −	+ and −	+	+
3. MgCl$_2$ vs. NaCl	+	+ and −	+ and −	+
4. KCl vs. NaCl	+ and −	+	+ and −	+ and −
5. KCl vs. MgCl$_2$	+ and −	+	+	....
6. CaCl$_2$ vs. NaCl	+ and —	+	+	—

+ = strong antagonism. + = mild antagonism. — = strong increase of toxicity − = slight increase of toxicity.

3. In regard to the effects of valences of ions the following results have been obtained with yeast :

(*a*) That divalent ions may antagonize monovalent ions is evident from the combinations of MgCl$_2$ vs. NaCl and CaCl$_2$ vs. NaCl. Ngative results were obtained from the combinations of KCl vs. CaCl$_2$ and KCl vs. MgCl$_2$.

(*b*) That a divalent ion may be antagonized by a divalent ion is evident from the combination of MgCl$_2$ vs. CaCl$_2$.

(*c*) That monovalent ions may antagonize divalent ions is shown in the combinations of KCl vs. CaCl$_2$; MgCl$_2$ vs. NaCl and KCl vs. MgCl$_2$.

(*d*) That a monovalent ion may antagonize a monovalent ion, though not very markedly, has been found in the combination of KCl vs. NaCl.

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CHANGES IN THE
CHEMICAL COMPOSITION OF GRAPES
DURING RIPENING

BY

F. T. BIOLETTI, W. V. CRUESS, and H. DAVI

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CHANGES IN THE CHEMICAL COMPOSITION

OF GRAPES DURING RIPENING

BY

F. T. BIOLETTI, W. V. CRUESS, AND H. DAVI

The investigations reported in this paper were undertaken to determine the changes in chemical composition of vinifera varieties of grapes in California during the growing and ripening stages. A survey of the literature indicated that, although the subject had been quite fully investigated in Europe with vinifera varieties and in America with the native varieties, very little had been published upon the ripening of vinifera varieties under California Conditions. A great many analyses of different varieties of grapes have been made by chemists of the University of California Experiment Station, notably by G. E. Colby, and are reported in the publications of this station.[1] A paper by G. E. Colby[2] gives data upon the nitrogen content of a number of varieties of ripe vinifera grapes. Most of the analyses, however, do not show the changes in composition during ripening.

Of the more recent European investigations[3] some deal with the changes in general composition, others are confined to a discussion of a single component, such as sugar, or coloring matter, or acid principles.

The changes in composition of American varieties of grapes during ripening have been studied quite thoroughly by W. B. Alwood[4] and his associates. These investigations gave particular attention to the

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increase in sugar content and changes in acidity during the period in which the grapes were under observation. Alwood and other members of the Bureau of Chemistry, United States Department of Agriculture, have also published a number of reports[4] on the general composition of American varieties of grapes as affected by season, locality, etc.

The most notable changes taking place during ripening were found by the European and American investigators mentioned above to be: (1) increase in total sugar; (2) decrease in ratio of glucose to fructose; (3) decrease in total acid; (4) increase in ratio of cream of tartar to total acid due to decrease in total acid; (5) decrease in tannin; and (6) increase in coloring matter. The cream of tartar and protein change very little in percentage during ripening, although, according to the

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investigations referred to, there is a slight increase in both of these constituents.

In the investigations reported in the present paper, particular attention was given to increase in total solids and sugar, decrease in total acid, and changes in protein and cream of tartar in the must or juice of the grapes. The ripening of the leaves was traced by noting the changes in starch, sugar, acid, and protein content.

Sampling.—During 1914 and 1915 samples of fruit were taken from the time the grapes had reached full size but were still hard and green until they had become overripe. During 1916 the first samples were taken shortly after the berries had set and before the seeds had formed. The last samples were taken when the grapes had become overripe. Samples of leaves were also taken in 1916 on the same dates that samplings of the grapes were made. The samples were taken at intervals of approximately one week. They were in all cases taken from the experimental vineyard at Davis.[5]

Five-pound samples of grapes were used. The grapes were picked from the first crop, except in 1914, when a comparison of the ripening of first and second crops was made. An ordinary five-pound grape basket was filled with leaves at each sampling. The samples of grapes and leaves were shipped from the vineyard to the laboratory at Berkeley, where the grapes were placed in an Enterprise fruit crusher and pressed. The juice was sterilized in bottles at 212° F. The leaves were ground in an Enterprise food chopper and sterilized at 212° F in wide mouth, air tight bottles. The samples were then reserved for chemical examination.

In 1914 it was found that there was considerable irregularity in the variation of samples from week to week. For example, instead of an increase of total solids during the periods between samplings, a slight decrease was found in a few samples. During the 1915 season it was therefore considered of interest to note what effect certain factors might have upon the composition of samples taken on the same date.

1. Effect of Age of Vine. The entire first crop from three large old vines and from three small young vines, all of the Muscat variety, was picked, crushed, and pressed. Analyses of the juices were made with the following results:

TABLE 1—EFFECT OF AGE OF VINE ON BALLING AND ACID OF MUST OF MUSCAT
GRAPES

Vine	Balling	Acid
Small, no. 1	24.7	.67
Small, no. 2	27.7	.49
Small, no. 3	27.6	.67
Large, no 1	22.0	.88
Large, no. 2	23.5	.75
Large, no. 3	23.6	.76
Average, small	26.7	.61
Average, large	23.0	.81
Difference	* 3.7	—.20

The results show rather strikingly that young vines ripen their fruit earlier than do mature vines. This fact makes it essential that samples, to be comparative, must be taken from vines of the same age.

2. Comparison of Grapes from North and South Sides of Vines
The whole first crop from three large Muscat vines was picked. The bunches from the north and south sides of each vine were kept separate. They were crushed, pressed, and analyzed for Balling and acid content.   ·

TABLE 2—COMPARISON OF BALLING AND ACID OF JUICE FROM GRAPES PICKED FROM
NORTH AND SOUTH SIDES OF VINES

Vine and side of vine	Balling	Acid
1 N	21.3	⸱ .92
1 S	22.7	.84
2-N	23.5	.81
2 S	23.5	.80
3-N	23.1	.81
3 S	24 1	.71
Average, N side	22.63	.85
Average, S side	23.43	.78
Difference	.80	—.07

The tests indicate that grapes located on the south side of the vine ripen more rapidly than those on the north side. This difference is apparently due to the fact that the south side of the vine receives more heat than the north side.

3. Effect of Location of Bunch on Cane. Grapes of first crop, from canes showing two bunches each, were picked and the bunches from near the bases of the canes kept separate from those near the tip of the cane. They were crushed, pressed, and analyzed for Balling and acid.

TABLE 3—EFFECT OF LOCATION OF BUNCH ON CANE

Vine	Nearest base of cane		Nearest tip of cane	
	Balling	Acid	Balling	Acid
Muscat, no. 1, cane 1	25.1	.73	23.7	.83
Muscat, no. 1, cane 2	25.6	.79	24.8	.80
Muscat, no. 2, cane 1	25.1	.85	24.6	.87
Muscat, no. 2, cane 2	25.2	.78	24.7	.85
Muscat, no. 3, cane 1	23.0	.79	22.6	.82
Muscat, no. 3, cane 2	24.5	.73	23.8	.73
Muscat, no. 4, cane 1	24.2	.90	25.2	.90
Muscat, no. 4, cane 2	24.5	.68	23.8	.83
Tokay, cane 1	21.2	.67	21.2	.80
Tokay, cane 2	23.0	.63	22.4	.76
Sultanina, cane 1	23.3	.61	22.3	.62
Sultanina, cane 2	22.5	.61	23.0	.63
Sultana, cane 1	23.2	.78	21.6	.70
Sultana, cane 2	21.1	.90	20.0	1.20
Palomino, cane 1	25.1		23 5	
Palomino, cane 2	22.0		23 7	
Means	24 9	.75	23 1	.81

The data indicate that bunches at the base of the cane ripen in most cases more rapidly than those near the tip, although this relation does not always hold and may be reversed in some instances.

4. Variation in Balling Degree of Must from Bunches of Similar Appearance and Size from Same Vineyard and Gathered on Same Date. A five-pound basket of grapes of first crop and selected for similarity of color, size of bunch, and general appearance was picked from each of a number of vines in the same vineyard. Vines of similar size and appearance were chosen. Several varieties were represented in the experiment. Tests of Balling degree only were made.

TABLE 4—VARIATION IN BALLING IN MUST FROM GRAPES OF SAME VARIETY PICKED FROM DIFFERENT VINES OF SIMILAR APPEARANCE

Variety	Vine number	Balling	Mean Balling	Maximum variation
Cornichon	3	14.5		
Cornichon	6	15.0		
Cornichon	9	14.2		
Cornichon	11	14.7		
Cornichon		16.1	14.9	1.9
Emperor	10	12.0		
Emperor	11	14.5		
Emperor	13	15.2		
Emperor	14	15.5		
Emperor	17	15.0	14.4	3.5
Malaga	5	18.5		
Malaga	6	17.2		

TABLE 4—(*Continued*)

Variety	Vine number	Balling	Mean Balling	Maximum variation
Malaga	7	19.7	......	......
Malaga	9	18.5	......	......
Malaga	11	19.2	18.6	2.0
Muscat	*	21.7	......	......
ᴧᴧuscat	*	21.1	......	......
Muscat	*	20.9	......	......
Muscat	*	21.5	......	......
Muscat	*	21.7	21.4	.8
Palomino	3	19.5	......	......
Palomino	4	21.0	......	......
Palomino	6	21.2	......	......
Palomino	7	20.7	......	......
Palomino	9	18.8	20.2	2.4
Sultanina	*	22.5	......	......
Sultanina	*	21.5	.. ...	......
Sultanina	*	18.7	......	......
Sultanina	*	22.0	......	......
Sultanina	*	22.6	21.5	3.9
Tokay	*	19.8	......	......
Tokay	*	19.3	....	......
Tokay	*	18.7	......	......
Tokay	*	20.7	......	......
Tokay	*	19.5	19.6	2.0
Pedro Zumbon	7	21.5	......	......
Pedro Zumbon	4	21.2	......	......
Pedro Zumbon	6	20.6	...... '	......
Pedro Zumbon	3	18.5	......	......
Pedro Zumbon	5	19.8	20.3	3.0
Emperor	15	18.1	......	......
Emperor	8	15.8	......	......
Emperor	14	16.2	......	......
Emperor	9	16.8	......	......
Emperor	16	16.3	16.6	2.3
Cornichon	4	17.3	......	......
Cornichon	9	16.3	......	. . ..
Cornichon	10	17.9	......	......
Cornichon	11	17.8	......	......
Cornichon	13	18.0	17.5	1.7
Malaga	4	18.3	......	......
Malaga	5	20.4	.. ...	. ...
Malaga	6	20.0	......	......
Malaga	8	20.1	19.7	1.8

Mean variation, six ripest varieties 2.32

Mean variation, six least ripe varieties 2.20

Average variation, whole series 2.30

* Adjacent vines.

The data illustrate the difficulty of selecting five-pound lots of the same variety that will represent average samples.

5. Effect of Location of Berries on the Bunch. All of the bunches of the first crop were taken from two Muscat vines. The bunches were cut into top and bottom halves. These lots were crushed separately, pressed, and the juices analyzed.

TABLE 5—EFFECT OF LOCATION OF BERRIES ON BUNCH

Sample	Balling	Acid
Vine no. 1, stem end of bunch	23.6	.76
Vine no. 1, apical end of bunch	22.7	.87
Vine no. 2, stem end of bunch	21.3	.92
Vine no. 2, apical end of bunch	21.3	.93

The results show that considerable variation in composition of the berries may exist within the same bunch.

6. Effect of Thoroughness of Pressing. About ten pounds of Muscat grapes were crushed and lightly pressed. The pulp and skins left from this pressing were then thoroughly crushed and pressed a second time. The juices from the two lots were analyzed separately.

TABLE 6—EFFECT OF THOROUGHNESS OF PRESSING

Sample	Balling	Acid
First pressing	22.8	.78
Second pressing	22.8	.79

There was practically no difference between the juices from lightly and thoroughly pressed grapes of the same lot.

The data from the above six tests indicate that it is a very difficult matter to select grapes that will represent a fair average sample of the grapes to be studied. The size and age of the vine, the side of the vines, the location of the bunch on the cane, and individual vines, all affect the composition of the juice from the grapes very materially, and these factors should be taken into account when samples are taken.

Preservation of Samples and Preparation for Analysis.—In 1914 the samples of juice were preserved with HgCl$_2$, 1:1000. In 1915 and 1916 the samples were sterilized at 100° C. Before analysis the bottles were heated to 100° C for an hour to dissolve any cream of tartar which might have separated. The juices were filtered before analysis. Considerable coagulation of dissolved solids took place during sterilization.

Methods of Analysis.—The samples were analyzed by the methods in use in the Agricultural Chemistry Laboratory and the Nutrition Laboratory of this station. A brief description of the methods follows:

1. Total Solids. The juice was filtered clear and cooled below 15° C. The specific gravity was determined by a pycnometer at 15°5 C. The corresponding total solids, or extract, was found from Windisch's tables in Leach's *Food Analysis,* page 697. This table gives the extract as "grams per 100 grams"; that is, per cent by weight. To calculate the corresponding grams per 100 c.c., the per cent by weight was multiplied by the specific gravity. This gives a figure not very much greater than grams per 100 grams in juices of low specific gravity, but gives a figure as much as 2 per cent greater where the total solids are much above 20 per cent. The two methods of reporting total solids has in the past led to much unnecessary confusion. It is therefore urged that the reader bear in mind the distinction between the two methods when reading the discussions in this paper or examining the curves.

2. Sugar. The sample was filtered; an aliquot was treated with lead acetate; diluted to mark; filtered; lead removed with anhydrous Na_2CO_3, and the sugar determined in an aliquot by the gravimetric method, using Soxhlet's modification of Fehling's solution. The Cu_2O was weighed directly after drying at 100° C. The corresponding sugar as invert sugar was obtained from Munson' and Walker's table in Leach's *Food Analysis.* The grams of invert sugar per 100 c.c. found in this way was divided by the specific gravity of the must to obtain the corresponding grams per 100 grams of juice.

3. Total acid was determined by titration of a 10 c.c. sample with N/10 NaOH, using phenolphthalein as an indicator, and is reported as tartaric acid, grams per 100 c.c.

4. Cream of tartar was estimated by a method suggested by Professor D. R. Hoagland of the Division of Agricultural Chemistry. Ten c.c. of the juice was incinerated at a low heat in a muffle furnace until well carbonized, but not to a white ash. (Excessive heating results in loss of K by volatilization.) The K_2CO_3 formed by incineration was leached out with hot water and a known excess of N/10 HCl added. This was titrated back with N/10 NaOH, using methyl orange as an indicator. The K_2CO_3 is obtained by difference and calculated back to cream of tartar, assuming that all of the K_2CO_3 is formed by the oxidation of cream of tartar, $KH(C_4H_4O_6)$. It is

reported as grams $KH(C_4H_4O_6)$ per 100 c.c., and, also as tartaric acid.

5. Free Tartaric Acid was obtained by difference between total acid and cream of tartar calculated as tartaric acid. It is reported as grams per 100 c.c.

6. Protein in the juice was determined by the usual Kjeldahl-Gunning method upon a 10 c.c. sample. It is reported as grams per 100 c.c.

7. Moisture in the leaves was determined by drying the sample at 100° C.

8. Sugar in the leaves was estimated by leaching the dried sample with cold water and determining sugar by the gravimetric Fehling method in the filtrate.

9. Starch in the leaves was determined by hydrolysis of the dried ground sample with dilute HCl at 100° C., followed by filtration and the usual gravimetric Fehling method for juice described above.

10. Protein in the leaves was determined by the Kjeldahl-Gunning method on .5 gram samples.

11. Acid in the leaves was estimated by leaching in hot water and titrating in the presence of the leaves, using litmus paper as indicator.

Analyses of Musts from Grape-Ripening Samples, 1914, 1915, 1916. The data from the analyses have been assembled in the following tables. Owing to the size of the tables, abbreviations have been necessary for the headings of the columns.

Explanations of Headings of Tables

1. Sp. gr. = Specific gravity at 15°5 C.
2. T. S. G. = Total solids in grams per 100 grams.
3. T. S. C. = Total solids in grams per 100 c.c.
4. S. G. = Sugar in grams per 100 c.c.
5. S. I. = Sugar in grams per 100 grams.
6. Tl. A. = Total acid in grams per 100 c.c.
7. C. T. = Cream of tartar in grams per 100 c.c.
8. C. T. T. = Cream of tartar as tartaric acid, grams per 100 c.c.
9. T. A. = Total free acid as tartaric obtained by subtracting cream of tartar as tartaric from total acid as tartaric.
10. P. = Protein, grams per 100 c.c.
11. S. = Sum of sugar, cream of tartar, tartaric acid, and protein in grams per 100 c.c.
12. T. S. —S. = Total solids (T. S. C.) —S (preceding column).

TABLE 7—GRAPE RIPENING TESTS, 1914

(Grapes from Davis)

Malaga

First crop:

Variety and date	1 Sp. gr.	2 T. S. G.	3 T. S. C.	4 S. G.	5 S. I.	6 Tl. A.	7 C. T	8 C.T.T.	9 T. A.	10 P.	11 S.	12 T. S. S.
Aug. 19	1.0396	10.25	10.65	7.32	7.04	2.78	.35	.13	2.65	.21	10.53	.12
Aug 26	1.0413	10.69	11.13	7.84	7.53	2.65	.36	.14	2.51	.25	10.96	.17
Aug. 26	1.0595	15.42	16.33	13.37	12.62	.77	.48	.19	.58	.55	14.98	1.41
Aug. 26	1.0613	15.87	16.84	14.31	13.50	1.46	.31	.12	1.34	.33	16.29	.55
Aug. 26	1.0694	18.01	19.25	16.59	15.52	1.00	.36	.14	.86	.38	18.19	1.06
Aug. 31	1.0732	19.00	20.39	17.65	16.45	.87	.55	.22	.65	.45	19.30	1.09
Sept. 23	1.0736	19.10	20.50	17.83	16.60	·.74	.38	.15	.59	.52	19.32	1.18
Oct. 5	1.0965	25.12	27.54	24.89	22.70	.72	.50	.20	.52	.57	26.48	1.06

Second crop:

Aug. 10	1.0213	5.51	5.62	2.07	2.03	3.22	.23	.09	3.13	.17	5.60	.02
Aug. 31	1.0495	12.82	13.45	9.58	9.13	2.51	.40	.16	2.35	.28	12.61	.84
Sept. 14	1.0532	13.78	14.51	11.89	11.30	2.07	.37	.15	1.92	.31	14.49	.02
Sept. 23	1.0670	17.43	18.60	15.29	14.33	1.54	.50	.20	1.35	.29	17.43	1.17
Sept. 23	1.0869	22.59	24.55	22.04	20.19	1.07	.45	.18	.89	.41	23.79	.76
Oct. 5	1.0930	24.20	26.45	23.90	21.87	.94	.48	.19	.75	.41	25.54	.91

Tokay

First crop:

Aug. 2	1.0454	11.75	12.28	8.73	8.35	2.63	.46	.18	2.45	.32	11.96	.32
Aug. 10	1.0624	16.08	17.08	14.28	13.44	1.56	.45	.18	1.38	.27	16.38	.70
Aug. 19	1.0682	17.69	18.90	15.94	14.92	1.32	.45	.18	1.14	.27	17.80	1.10
Aug. 31	1.0849	22.09	23.97	21.87	20.16	.63	.59	.23	.40	.40	23.26	.71
Sept. 4	1.0865	22.49	24.44	22.21	20.44	.77	.43	.17	.60	.32	23.56	.88
Sept. 4	1.0912	23.72	25.88	23.44	21.48	.59	.64	.25	.44	.41	24.93	.95
Sept. 23	1.0937	24.38	26.66	24.15	22.08	.58	.49	.19	.30	.39	25.33	1.33
Oct. 14	1.0991	25.80	28.36	25.55	23.25	.45	.54	.21	.24	.45	26.78	1.58
Oct. 14	1.1000	26.04	28.64	25.78	23.44	.52	.58	.23	.29	.58	27.23	1.41

Second crop:

Aug. 19	1.0657	17.04	18.16	15.03	14.10	1.91	.50	.20	1.70	.32	16.55	.61
Sept. 14	1.0701	18.19	19.47	16.68	15.59	1.29	.52	.21	1.11	.33	18.64	.83
Sept. 23	1.0769	19.95	21.48	19.22	17.85	1.01	.48	.19	.82	.40	20.92	.56
Oct. 14	1.0911	23.70	25.86	23.43	21.47	.69	.60	.24	.45	.40	24.88	.98

TABLE 8—GRAPE RIPENING TESTS, 1915

(Grapes from Davis)

ι ornichon

Variety and date	1 Sp. gr.	2 T. S. G.	3 T S.C.	4 S. G:	5 S. I.	6 Tl. A.	7 C. T.	8 C.T.T.	9 T.A.	10 P.	11 S.	12 T. S. S.
Aug. 22	1.0324	8.38	8.65	3.99	3.86	3.05	.58	.23	2.82	.38	7.77	.88
Sept. 1	1.0514	13.31	13.99	10.70	10.18	1.62	.61	.25	1.37	.42	13.10	.89
Sept. 15	1.0688	17.85	19.08	15.94	14.91	.97	.70	.28	.69	.43	17.76	1.32
Sept. 22	1.0723	18.76	20.12	16.97	15.83	.94	.71	.28	.66	.46	18.80	1.32
Sept. 29	1.0737	19.13	20.54	18.31	17.05	.87	.75	.30	.61	.66	20.33	.21
Oct. 7	1.0781	20.28	21.86	19.41	18.02	.71	.73	.29	.42	.48	21.04	.82
Oct. 14	1.0843	21.91	23.76	20.40	18.81	.78	.68	.27	.62	.66	22.36	1.40
Oct. 22	1.0873	22.70	24.68	21.06	19.37	.75	.78.	.31	.44	.46	22.74	1.94

<center>TABLE 8—(*Continued*)</center>

Emperor

Variety and date	1 Sp. gr.	2 T. S. G.	3 T. S. C.	4 S. G.	5 S. I.	6 Tl. A.	7 C. T.	8 C.T.T.	9 T. A.	10 P.	11 S.	12 T. A. S.
Aug. 19	1.0420	10.87	11.33	6.96	6.68	2.33	.38	.15	2.18	.38	9.90	1.43
Sept. 1	1.0479	12.40	12.99	9.82	9.37	1.89	.40	.16	1.73	.62	12.57	.42
Sept. 7	1.0560	14.51	15.32	11.48	10.87	1.70	.47	.19	1.57	.54	14.00	1.32
Sept. 15	1.0632	16.37	17.40	14.88	14.00	1.40	.53	.21	1.18	.54	17.13	.27
Sept 22	1.0652	16.91	18.01	15.46	14.51	.93	.48	.19	.74	.55	17.23	.78
Sept. 29	1.0672	17.43	18.60	16.37	15.34	.91	.48	.19	.72	.66	18.23	.37
Oct. 7	1.0744	19.31	20.75	17.82	16.59	.79	.58	.23	.56	.51	19.47	1.28
Oct. 14	1.0765	19.86	21.38	18.37	17.06	.79	.59	.24	.56	.63	20.15	1.23
Oct. 22	1.0792	20.57	22.20	19.81	18.36	.75	.63	.25	.49	.66	21.59	.61

Malaga

Variety and date	1 Sp. gr.	2 T. S. G.	3 T. S. C.	4 S. G.	5 S. I.	6 Tl. A.	7 C. T.	8 C.T.T.	9 T. A.	10 P.	11 S.	12 T. A. S.
Aug. 19	1.0546	14.14	14.91	12.47	11.82	2.05	.36	.15	1.90	.75	15.48	.57
Aug. 25	1.0651	16.86	17.96	14.53	13.64	1.66	.46	.18	1.48	.90	17.37	.59
Sept. 1	1.0678	17.59	18.78	16.75	15.69	1.38	.44	.18	1.20	.89	19.28	.50
Sept. 7	1.0719	18.66	19.50	17.00	15.86	1.29	.44	.18	1.11	.70	19.25	.25
Sept. 15	1.0758	19.68	21.17	18.17	16.89	1.21	.62	.25	.96	.70	20.45	.72
Sept. 22	1.0760	19.81	21.32	18.39	17.09	1.18	.61	.25	.93	.74	20.67	.65
Sept. 29	1.0812	21.20	22 92	18.48	17.09	1.07	.58	.23	.84	.75	20.65	2.27
Oct. 7	1.0838	21.78	23.61	21.03	19.40	1.07	.65	.26	.81	.73	23.22	.39
Oct. 14	1.0970	25.25	27.70	24.58	22.41	.59	.83	.33	.26	.88	26.55	1.15

Muscat

Variety and date	1 Sp. gr.	2 T. S. G.	3 T. S. C.	4 S. G.	5 S. I.	6 Tl. A.	7 C. T.	8 C.T.T.	9 T. A.	10 P.	11 S.	12 T. A. S.
Aug. 19	1.0615	15.94	16.92	13.93	13.12	1.70	.36	.15	1.55	.70	16.54	.38
Aug. 25	1.0744	19.31	20.75	17.96	16.72	1.21	.62	.25	.96	.62	20.16	.59
Sept. 1	1.0805	20.91	22.59	19.50	18.05	.79	.63	.25	.54	.63	21.30	1.29
Sept. 7	1.0827	21.47	23.25	20.39	18.83	.76	.65	.26	.50	.66	22.20	1.05
Sept. 15	1.0917	23.85	26.04	23.49	21.52	.96	.58	.23	.73	.58	25.38	.66
Sept. 22	1.0954	24.14	26.44	24.54	22.40	.77	.62	.25	.52	.85	26.53	.09
Sept. 29	1.1048	27.30	30.16	27.01	24.45	.72	.72	.29	.44	.72	28.89	1.27
Oct. 7	1.1079	28.12	31.15	28.28	25.53	.66	.59	.23	.43	.66	29.96	1.19

Pedro Zumbon

Variety and date	1 Sp. gr.	2 T. S. G.	3 T. S. C.	4 S. G.	5 S. I.	6 Tl. A.	7 C. T.	8 C.T.T.	9 T. A.	10 P.	11 S.	12 T. A. S.
Aug. 19	1.0555	14.38	15.18	11.96	11.33	1.81	.68	.27	1.54	.33	14.51	.67
Aug. 25	1.0588	15.24	16.14	13.77	13.01	1.09	.57	.23	.86	.53	15.73	.41
Sept. 1	1.0642	16.64	17.71	15.61	14.67	.58	.52	.21	.37	.43	16.93	.78
Sept. 7	1.0693	17.98	19.23	16.55	15.48	.84	.48	.19	.65	.73	18.41	.82
Sept. 15	1.0708	18.37	19.67	18.17	16.97	.56	.58	.23	.33	.64	19.72	.05
Sept. 22	1.0912	23.72	25.88	23.02	21.10	.53	.87	.35	.19	.64	24.72	1.16

Sultana

Variety and date	1 Sp. gr.	2 T. S. G.	3 T. S. C.	4 S. G.	5 S. I.	6 Tl. A.	7 C. T.	8 C.T.T.	9 T. A.	10 P.	11 S.	12 T. A. S.
Aug. 19	1.0673	17.80	19.00	15.63	16.64	1.69	.33	.13	1.56	.32	17.84	1.16
Aug. 25	1.0746	19.37	20.82	17.96	16.71	1.44	.37	.14	1.30	.38	20.01	.81
Sept. 1	1.0815	21.17	22.90	20.26	18.73	1.14	.54	.22	.92	.50	22.22	.68
Sept. 7	1.0893	23.22	25.29	23.02	21.13	.78	.44	.18	.60	.34	24.40	.89
Sept. 22	1.0902	23.39	25.50	23.10	21.19	1.24	.50	.20	1.04	.38	25.02	.48
Sept. 29	1.0922	23.99	26.20	24.04	22.01	.80	.41	.17	.63	.42	25.50	.70

TABLE 8—(*Continued*)

Sultanina

Variety and date	1 Sp. gr.	2 T. S. G.	3 T. S. C.	4 S. G.	5 S. I.	6 Tl. A.	7 C. T.	8 C.T.T.	9 T. A.	10 P.	11 S.	12 T. A. S.
Aug. 19	1.0673	17.46	18.64	15.87	14.87	1.27	.44	.18	1.09	.42	17.82	.82
Aug. 25	1.0743	19.26	20.69	18.30	17.03	1.19	.47	.19	1.00	.37	20.14	.55
Sept. 1	1.0771	20.02	21.56	18.98	17.62	.85	.49	.20	.65	.42	20.54	1.02
Sept. 7	1.0892	23.20	25.27	22.42	20.58	.72	.80	.32	.40	.62	24.24	1.03
Sept. 15	1.0927	24.12	26.36	23.62	21.62	.79	.76	.30	.39	.45	25.22	1.14
Sept. 22	1.0984	25.62	28.14	25.71	23.41	.60	.58	.23	.37	.45	27.11	1.03
Sept. 29	1.1049	27.33	30.20	27.41	24.81	.54	.51	.20	.34	.42	28.68	1.52

Tokay

Variety and date	1 Sp. gr.	2 T. S. G.	3 T. S. C.	4 S. G.	5 S. I.	6 Tl. A.	7 C. T.	8 C.T.T.	9 T. A.	10 P.	11 S.	12 T. A. S.
Aug. 19	1.0598	15.50	16.43	14.41	13.60	1.74	.41	.16	1.58	.29	16.69	.26
Aug. 25	1.0676	17.54	18.73	15.63	14.64	1.24	.39	.15	1.09	.69	17.80	.93
Sept. 1	1.0757	19.65	21.14	18.17	16.89	.84	.47	.19	.66	.44	19.74	1.40
Sept. 7	1.0781	20.28	21.86	19.11	17.73	.79	.45	.18	.61	.37	20.54	1.32
Sept. 15	1.0785	20.39	21.99	19.26	17.86	.74	.48	.19	.55	.40	20.69	1.30
Sept. 22	1.0798	20.73	22.38	20.17	18.68	.59	.51	.20	.39	.36	21.43	.95
Sept. 29	1.0823	21.38	23.14	20.76	19.18	.85	.58	.23	.62	.28	22.24	.90
Oct. 7	1.0830	21.57	23.36	20.87	19.27	.69	.63	.25	.44	.42	22.36	1.00
Oct. 14	1.0851	22.12	24.00	21.53	19.84	.65	.69	.28	.38	.36	22.96	1.04
Oct. 22	1.0895	23.28	25.36	22.91	21.03	.66	.72	.29	.37	.37	24.37	.99

TABLE 9—GRAPE RIPENING TESTS, 1916

Burger

Variety and date	1 Sp. gr.	2 T S G.	3 T. S. C.	4 S G.	5 S. I.	6 Tl. A.	7 C. T. T	8 C.T.T	9 T. A.	10 P.	11 S	12 T. S. S.
June 12	1.0212	5.48	5.59	1.29	1.55	2.95	.55	.22	2.73	.44	5.27	.32
June 19	1.0195	5.04	5.88	.87	.88	2.88	.51	.21	2.67	.45	4.51	1.37
June 27	1.0220	5.69	5.82	1.25	1.28	2.94	.33	.13	2.81	.45	4.87	.95
July 7	1.0220	5.69	5.82	1.11	1.28	2.98	.49	.20	2.78	.31	4.86	.96
July 10	1.0200	5.17	5.27	.93	.95	3.32	.57	.23	3.09	.37	4.97	.30
July 19	1.0205	5.30	5.41	1.03	1.05	3.13	.55	.22	2.91	.35	4.86	.55
July 27	1.0225	5.82	5.95	1.13	1.15	2.93	.48	.19	2.74	.34	4.71	1.24
Aug. 3	1.0258	6.67	6.84	2.14	2.19	2.71	.63	.25	2.46	.40	5.68	1.16
Aug. 7	1.0330	8.53	8.83	3.36	3.46	2.67	.87	.35	2.32	.47	7.12	1.21
Aug. 16	1.0391	10.11	10.51	5.90	6.13	2.41	.95	.38	2.03	.46	9.57	.94
Aug. 23	1.0422	10.92	11.38	6.03	6.27	2.10	.98	.39	1.71	.63	9.59	1.89
Aug. 30	1.0529	13.70	14.42	9.95	10.42	1.15	1.03	.41	.74	.49	12.70	1.72
Sept. 5	1.0645	16.73	17.81	14.51	15.43	1.01	1.07	.43	.68	.61	17.79	.02
Sept. 12	1.0717	18.61	19.94	16.27	17.36	.95	.98	.39	.56	.82	19.72	.22
Sept. 20	1.0765	19.86	21.37	17.44	18.73	.87	1.06	.42	.45	.62	20.86	.51
Sept. 26	1.0808	20.99	22.68	18.48	19.99	.81	1.01	.40	.41	.83	22.24	.44

Cornichon

Variety and date	1 Sp. gr.	2 T S G.	3 T. S. C.	4 S G.	5 S. I.	6 Tl. A.	7 C. T. T	8 C.T.T	9 T. A.	10 P.	11 S	12 T. S. S.
June 12	1.0202	5.22	5.32	.91	.93	3.15	.64	.26	2.89	.32	4.78	.54
June 19	1.0200	5.17	5.27	.86	.88	2.96	.62	.25	2.71	.42	4.63	.64
June 27	1.0193	4.99	5.08	.84	.86	2.89	.39	.16	2.73	.56	4.54	.44
July 7	1.0201	5.19	5.29	.87	.89	2.88	.44	.18	2.70	.52	4.55	.74
July 10	1.0206	5.32	5.43	.85	.87	3.27	.54	.22	3.05	.53	4.99	.44
July 19	1.0225	5.82	5.95	1.28	1.30	3.11	.57	.23	2.88	.55	5.30	.65
July 27	1.0242	6.25	6.40	1.63	1.66	2.94	.54	.22	2.72	.44	5.26	.14
Aug. 3	1.0373	9.65	10.00	5.00	5.19	2.87	.59	.24	2.63	.56	8.97	1.03

TABLE 9—(*Continued*)

Variety and date	1 Sp. gr.	2 T. S. G.	3 T. S. C.	4 S. G.	5 S. I.	6 Tl. A.	7 C. T.	8 C.T.T.	9 T. A.	10 P.	11 S.	12 T. A. S.
Aug. 7	1.0375	9.70	10.06	5.28	5.48	2.79	.65	.26	2.53	.66	9.32	.64
Aug. 16	1.0434	11.23	11.71	6.30	6.57	2.75	1.06	.43	2.32	.53	10.48	1.23
Aug. 23	1.0635	16.47	17.51	12.19	12.96	1.85	1.06	.43	1.42	.58	16.02	1.49
Aug. 30	1.0685	17.77	18.97	14.75	15.61	1.16	1.10	.44	.72	.63	18.06	.91
Sept. 5	1.0694	18.01	19.25	15.03	16.07	.93	.90	.36	.57	.58	18.12	1.13
Sept. 12	1.0757	19.65	21.09	16.37	17.60	.87	1.14	.46	.41	.78	19.97	1.12
Sept. 20	1.0786	20.41	22.00	17.52	18.88	.84	.94	.37	.44	.59	20.85	1.15
Sept. 26	1.0828	21.52	23.30	18.52	20.03	.72	.83	.33	.39	.85	22.10	1.20

Muscat

June 12	1.0203	5.25	5.35	.91	.93	2.93	.65	.26	2.71	.38	4.67	.68
June 19	1.0199	5.14	5.24	.70	.72	3.37	.63	.25	3.12	.44	4.91	.33
June 27	1.0210	5.43	5.54	1.33	1.36	3.33	.48	.19	3.14	.49	5.47	.07
July 7	1.0210	5.43	5.54	1.63	1.66	3.32	.54	.22	3.10	.45	5.75	.21
July 10	1.0195	5.04	5.14	1.33	1.36	3.60	.55	.22	3.38	.36	5.65	.51
July 19	1.0251	6.49	6.65	2.55	2.61	3.40	.58	.23	3.17	.49	6.85	.20
July 27	1.0308	7.97	8.22	3.56	3.67	2.67	.66	.26	2.01	.45	6.79	1.43
Aug. 3	1.0488	12.64	13.26	9.72	10.19	1.77	.68	.27	1.50	.46	12.83	.43
Aug. 7	1.0582	15.68	16.58	12.72	13.53	1.60	.73	.29	1.31	.55	16.12	.46
Aug. 16	1.0803	20.86	22.53	16.81	18.15	1.16	.94	.38	.78	.51	20.38	1.70
Aug. 23	1.0910	23.67	25.82	20.20	22.04	.82	1.04	.42	.40	.56	24.04	1.78
Aug. 30	1.0972	25.30	27.75	21.87	22.99	.65	1.21	.49	.16	.58	25.94	1.81
Sept. 5	1.1023	26.64	29.36	23.28	24.74	.60	1.17	.47	.13	.65	26.69	2.67
Sept. 12	1.1101	28.70	31.85	25.95	27.83	.56	1.35	.54	.02	.69	29.89	1.96
Sept. 20	1.1122	29.25	32.72	26.43	29.39	.68	1.56	.63	.05	.58	31.27	1.45
Sept. 26	1.1133	29.54	32.89	26.68	29.70	.56	1.39	.56	.00	.59	31.57	1.32

TABLE 10—CATAWBA GRAPE RIPENING TESTS

(Table from U. S. Dept. Agric. Bulletin 335, by W. B. Alwood)

Catawba
1912:

Variety and date	1 Sp. gr.	2 T. S. G.	3 T. S. C.	4 S. I.	5 S G.	6 Tl A.	7 C. T.	8 C T. T.	9 Days
Sept. 4	1.0329	8.51	8.84	3.60	3.72	3.68	.39	.16	0
Sept. 9	1.0419	10.84	11.29	6.68	6.96	3.02	.41	.16	5
Sept. 12	1.0515	13.34	14.03	9.35	9.78	2.48	.46	.18	8
Sept. 17	1.0537	13.91	14.66	10.38	10.95	2.12	.45	.18	13
Sept. 24	1.0569	14.74	15.58	11.33	11.96	1.74	.53	.21	20
Oct. 1	1.0614	15.92	16.89	12.75	13.48	1.63	.54	.22	27
Oct. 7	1.0663	17.20	18.34	13.79	14.71	1.53	.61	.24	33
Oct. 16	1.0725	18.82	20.18	15.35	16.46	1.34	.61	.24	42
Oct. 23	1.0716	18.58	19.90	15.01	16.09	1.28	.59	.24	47
Oct. 29	1.0769	19.97	21.50	16.49	17.75	1.22	.57	.23	53
Nov. 4	1.0790	20.52	22.14	16.77	18.08	1.28	.71	.28	59
Nov. 8	1.0755	19.60	21.07	16.39	17.61	1.09	.52	.21	63

Curves of Total Solids, Sugar, Total Acid, Free Acid, and Cream of Tartar.—In order to present the data in a form in which they may be readily studied, graphs have been constructed using time in days as abscissae and the above constituents expressed in grams per 100 c.c. as ordinates. The curves represent the data for 1914, 1915, and 1916. For comparison, curves of the changes in composition of Catawba grapes reported by W. B. Alwood in the United States Department of Agriculture Bulletin 335 have been included. The acid principles have been plotted to a scale five times as great as that used for total solids and sugar in order that the variations in acidity might be more apparent.

Discussion of Graphs of Total Solids, Sugar, Total Acid, Cream of Tartar, and Free Acid.—(1) Total Solids and Sugar. The data are more complete for 1916 than for 1914 or 1915, and include the period during which the berries are growing to full size as well as the ripening period itself, during which the rapid increase in sugar occurs. The curves for 1916, therefore, are of more interest than those for 1914 and 1915. In the case of the Burger variety, total solids and sugar remained constant for approximately forty days after the tests were started. There was then a slight rise in these components for a period of about ten days. From that point on the rise in total solids and sugar was very rapid and fairly uniform. The behavior of the Cornichon was very similar.   .

The Muscat began ripening about ten days earlier than the Burger and Cornichon, and proceeded much more rapidly up to about the ninetieth day after the experiment was started. There was then a slowing up in the increase in total solids and sugar corresponding to the period of over-ripeness. This slower increase in total solids is also evident in the curves for Emperor, Muscat, Sultana, and Tokay for the 1915 season, and would undoubtedly show in all cases if the observations were continued sufficiently.

The effect of the season upon the rate of ripening is shown by a comparison of the Cornichon and Muscat varieties for 1915 and 1916. All varieties ripened more slowly in 1915 than in 1916, resulting in steeper curves for 1916. However, owing to the fact that sampling was started later in 1914 and 1915 than in 1916, the curves for the former two years show only the changes taking place during the latter half of the ripening period. No very close comparisons therefore can be made of the three years.

The Catawba reported by Alwood, and for which curves appear
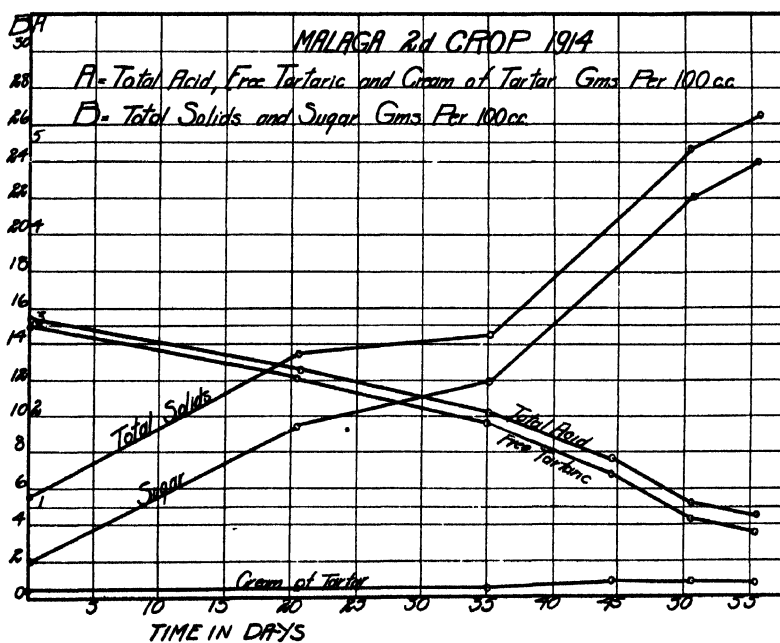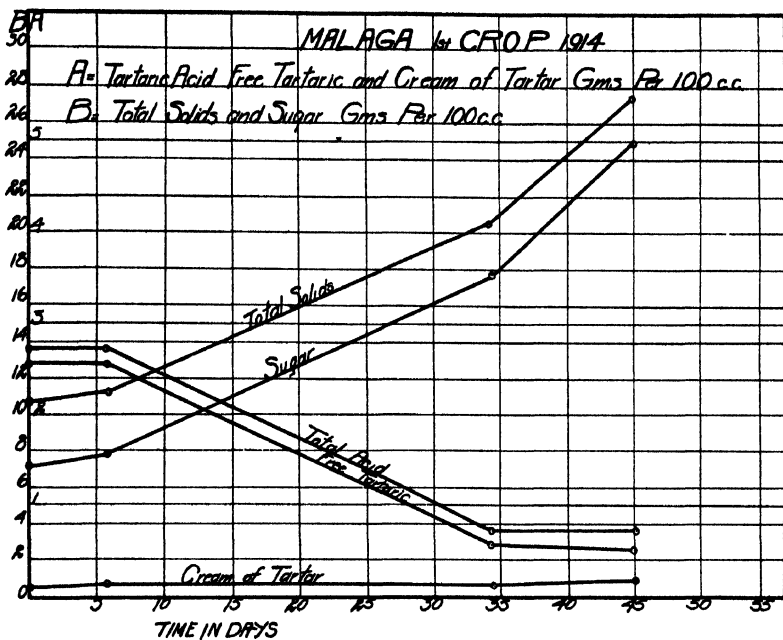
Fig. 1—Malaga first and second crops, 1914.
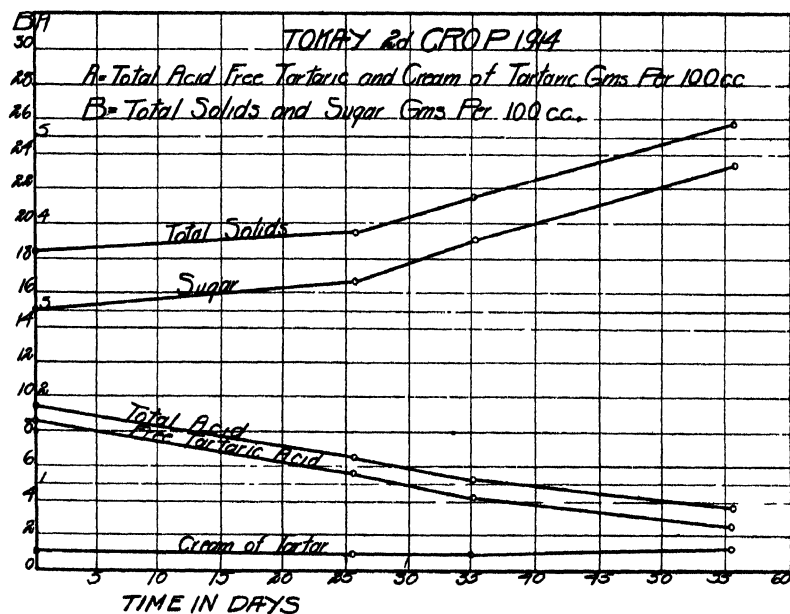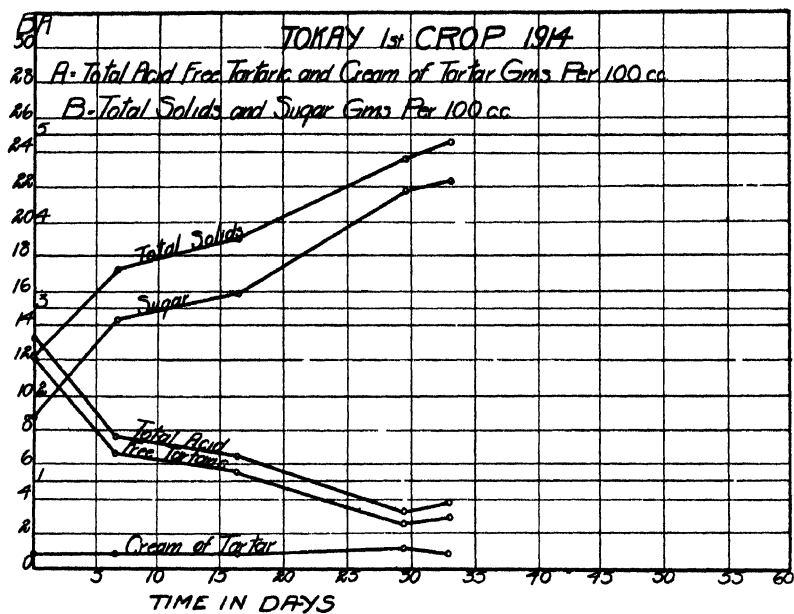
Fig. 2—Tokay first and second crops, 1914.

. 3—Cornichon and Emperor, 1915.
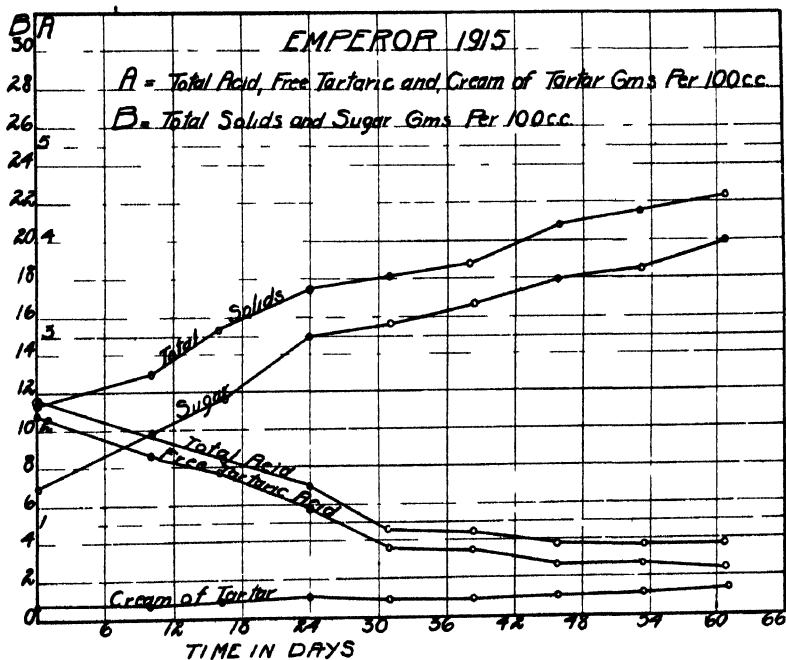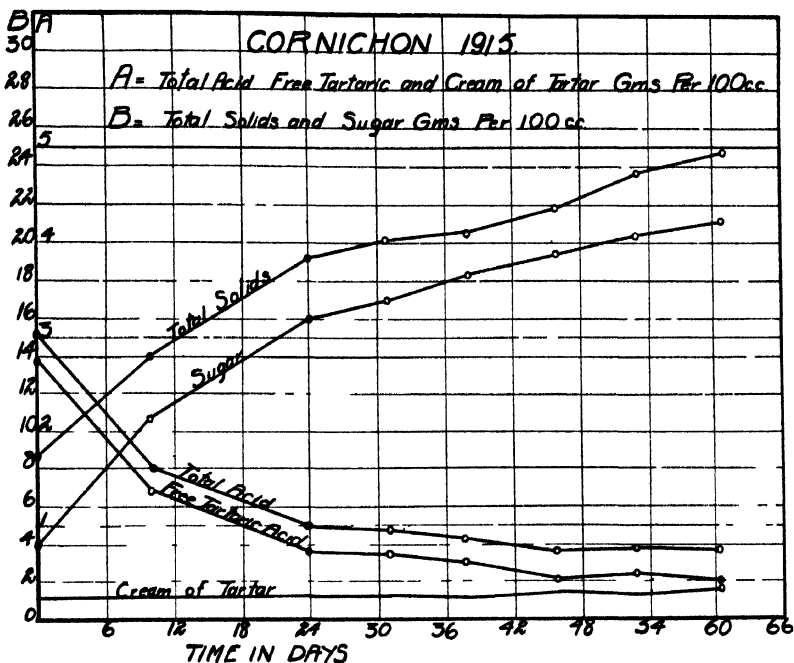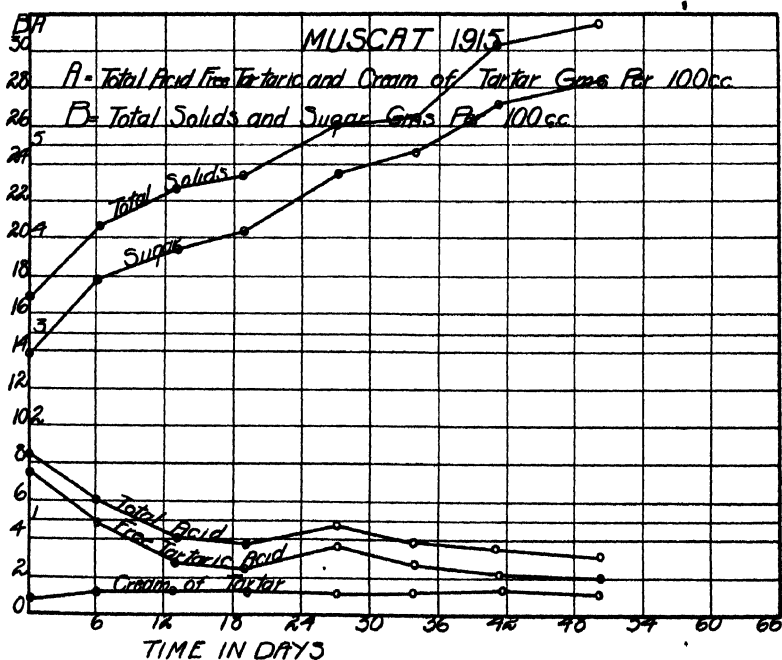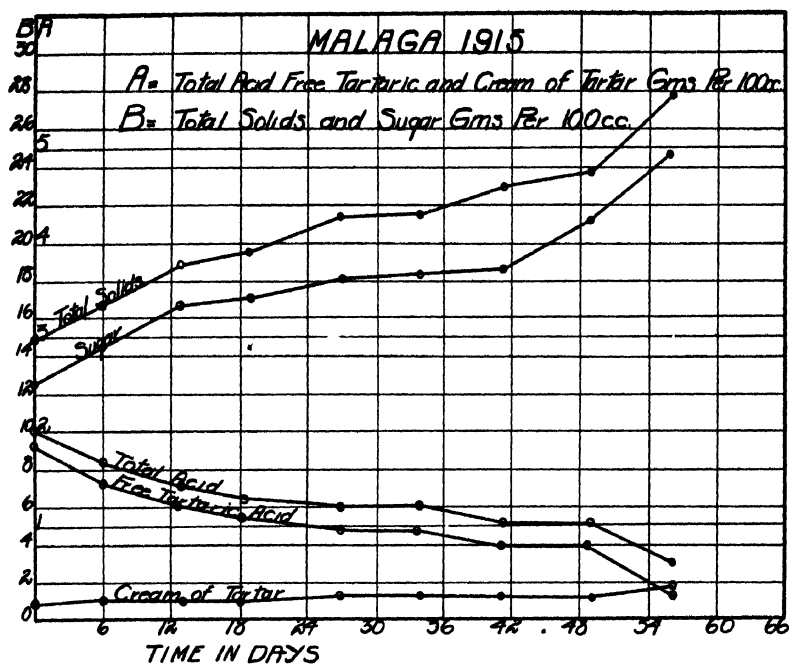
Fig. 4—Malaga and Muscat, 1915.
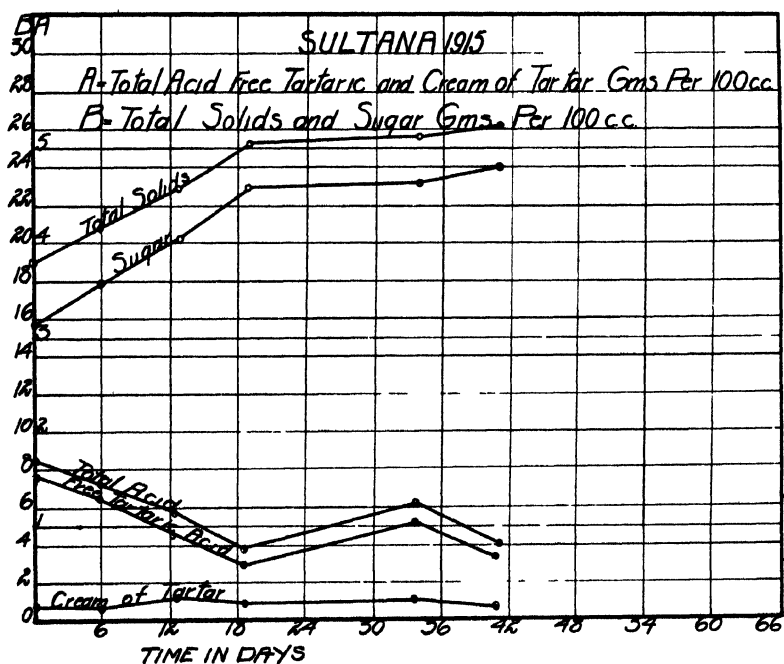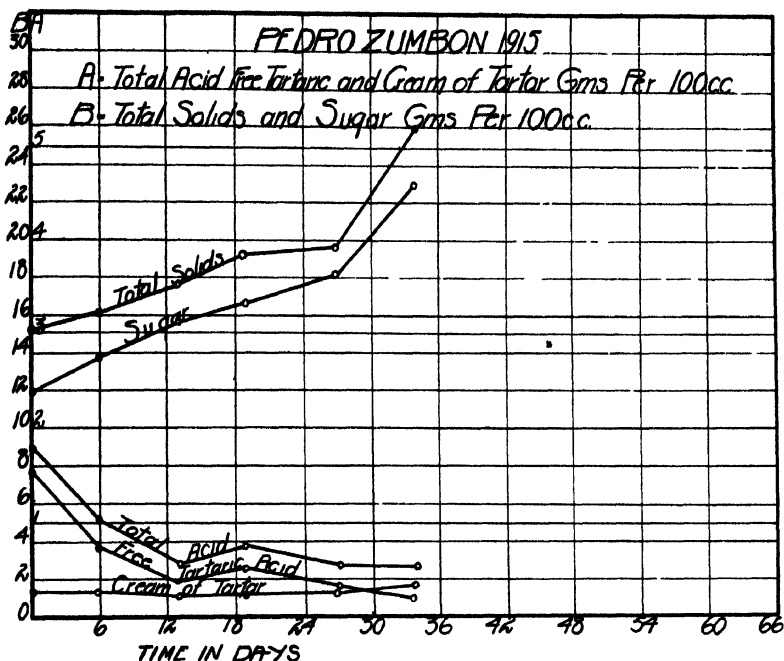
Fig. 5—Pedro Zumbon and Sultana, 1915.
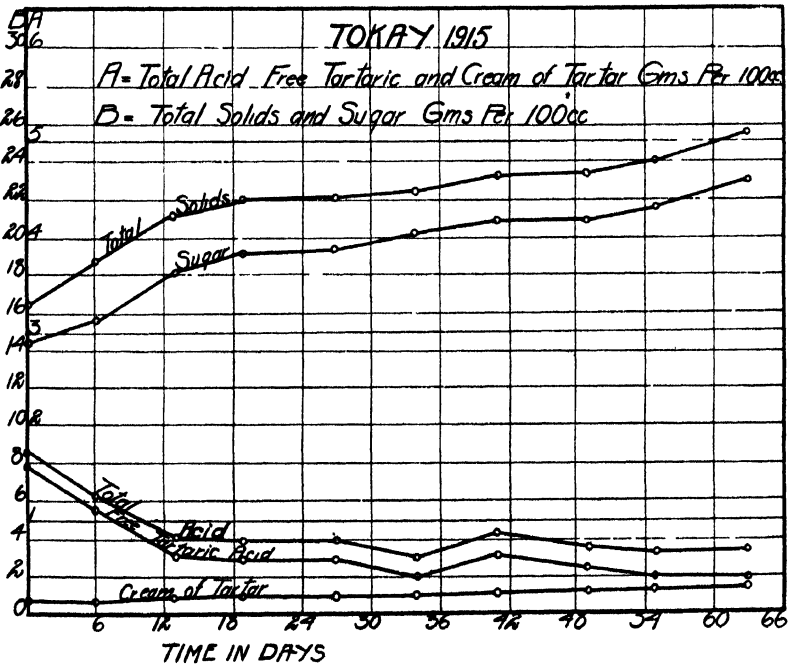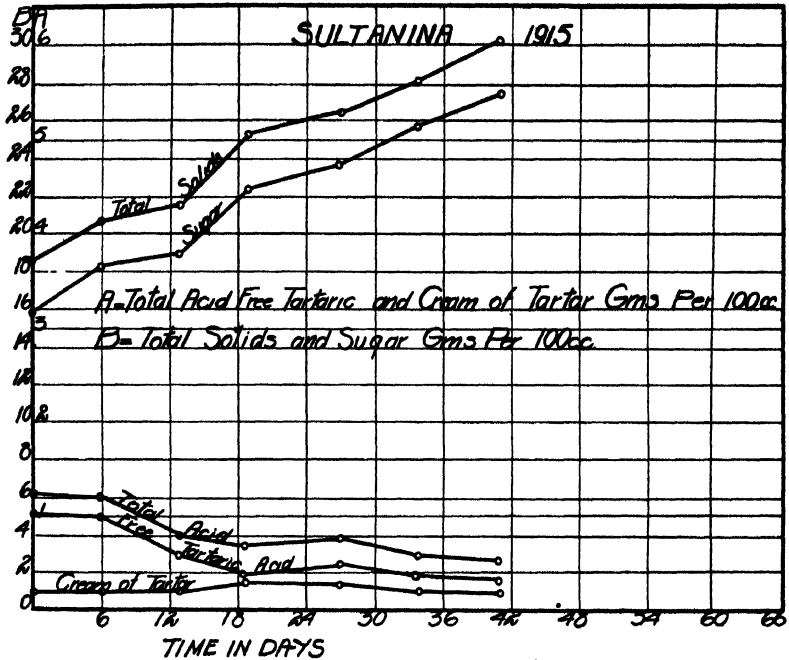
Fig. 6—Sultanina and Tokay, 1915.
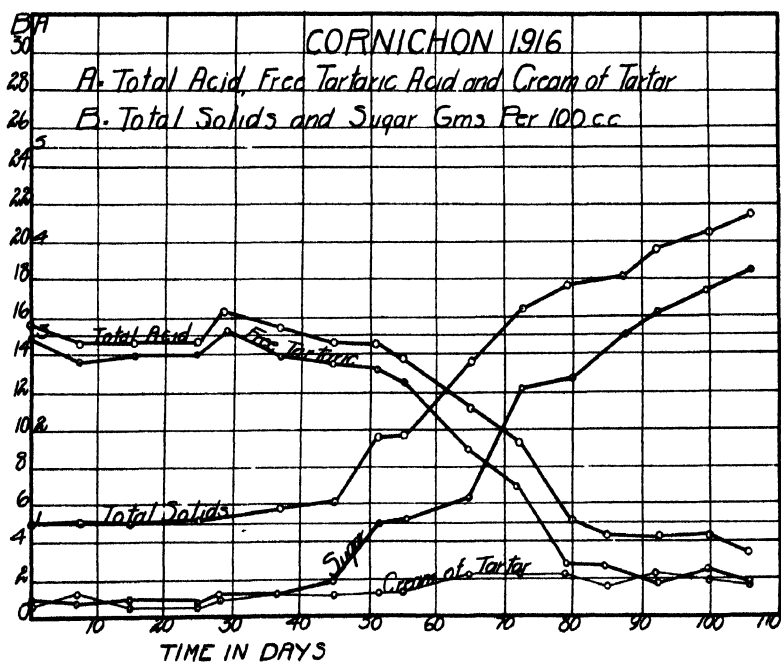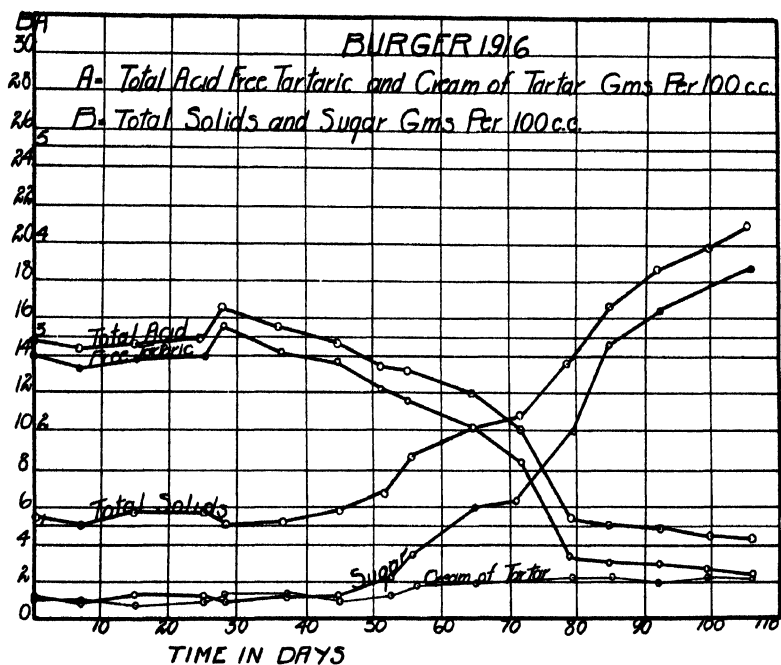
Fig. 7—Burger and Cornichon,.1916.
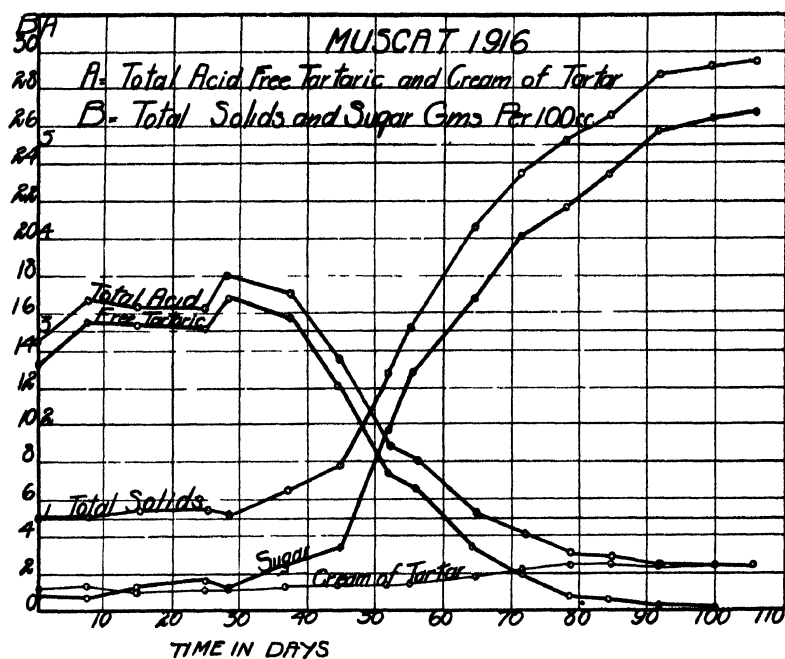
Fig. 8—Muscat, 1916.
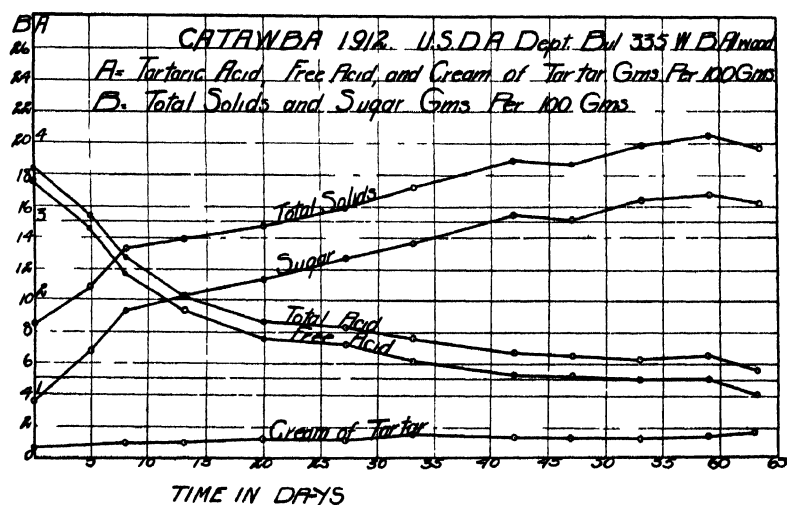
Fig. 9—Catawba (U. S. Dept. Agric. Bull. 335).

in figure 9, ripened more slowly than the Vinifera varieties. For example, during a period of fifty days, the total solids increased only 4 per cent. It can not be said from the data at hand whether this slow ripening is due to the conditions under which the grapes were grown or to the variety.

By reference to figures 1 and 2 it may be seen that the general form of the ripening curves is the same for the first and for second crop. In one case, the Malaga, the curves are almost identical for the period common to both, i.e., from 10.6 Bal. to 26.3 Bal., showing an equal rate of ripening. In the other, the Tokay, the curve of the second crop, from 18.2 Bal. to 24.6 Bal., is much flatter than that of the first, indicating a rate of ripening with the latter of about two and a half times that of the former. This difference can be accounted for by the cooler weather during the time the second crop Tokay was ripening, which was about ten days later than in the case of the second crop Malaga. The slower ripening is probably due both to the direct effect of the cool weather and to the decreased activity of the leaves at lower temperatures.

(2) Changes in Total Acid, Cream of Tartar, and Free Acid. Owing to the fact that the analyses were started in 1914 and 1915 after ripening had commenced, the curves for these years show a decrease in acid throughout the period of the tests. In 1916, however, a rise in total acid occurred during the growing stage, as shown by a rise in the curve during the first thirty days of the experiment. Although this rise is not very large, it is quite definite, and occurs in all three varieties tested. The rise was most positive in the case of the Muscat grape, and amounted to .67 per cent acid as tartaric. From the point of maximum acidity, the total decreases slowly until the period of rapid ripening sets in. The total acid then decreases very rapidly for a time and more or less in proportion to the increase in total solids and sugar. As the grapes near maturity, the rate of decrease of total acid becomes less and the total remains practically constant after the grapes have reached maturity.

The cream of tartar in general increases very slightly during the periods of growth and ripening.

The increase in total acid during the first stages of growth is due to increase in the free acid. Since the cream of tartar remains almost constant throughout the ripening period, the curve of the free acid is practically parallel with that of the total acid.

As the grapes approach maturity, the cream of tartar calculated as

tartaric acid approaches the total acid, and in one case, (Musct, 1916), actually became equal to the total acid, indicating that in this instance no free acid remained.

Second crop grapes were found to be higher in free acid than first crop grapes of the same total solids and sugar content. The Catawba grape grown under eastern conditions (fig. 9) exhibits relatively high free acid. Alwood[6] has found this free acidity in eastern grapes to be due largely to malic acid. No attempt was made in the analyses of the California samples to identify the various acids making up the free acidity which was calculated as tartaric acid.

Mean Differences Between Total Solids and Sugar.—The following table contains figures representing the differences between total solids and sugar at the various percentages of total solids indicated at the tops of the columns. The data represent a range of total solids from 5 per cent to 30 per cent. The figures were taken from the data reported in tables 7 to 9, and represent several varieties of grapes. Only a few determinations of total solids and sugar were available for the lower concentrations (5 per cent to 15 per cent), and therefore the figures for this range may not represent averages so accurately as the figures above 15 per cent total solids.

Between 5 per cent and 11 per cent solids, the average difference between total solids and sugar remains practically constant. From 11 per cent to 17 per cent total solids, the mean difference decreases quite rapidly. From 17 per cent to 30 per cent, the difference remains fairly constant. The variations noted after 17 per cent total solids
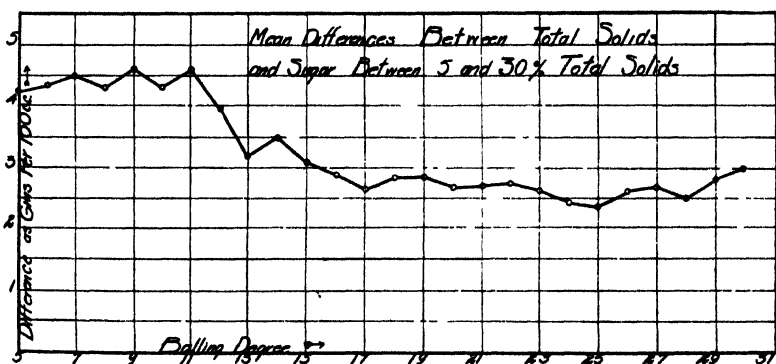
Fig. 10—Mean differences between total solids and sugar between 5 per cent and 30 per cent total solids.

[6] U. S. Dept. Agric. Bull. 335.

TABLE 11—MEAN DIFFERENCES BETWEEN TOTAL SOLIDS AND SUGAR

(Figures in columns represent difference between total solids and sugar for various juices of total solids content indicated at tops of columns)

5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
4.4	3.9	4.5	4.4	4.6	4.6	4.9	4.0	2.9	3.8	3.8	2.9	2.9	2.9	2.6	1.5	1.7	2.0	2.1	2.2	2.5	2.9	2.9	2.9	2.8	2.9
4.2	4.5		4.2	4.6	4.2	4.9	3.8	3.2	3.5	3.2	3.4	3.0	2.7	2.7	3.2	3.1	3.6	4.2	2.6	2.6	2.8	2.5	2.6	2.8	3.1
4.2	4.7				4.4	4.1		3.5	3.2	2.3	3.3	3.3	3.3	3.3	2.3	2.7	2.5	3.0	3.5	2.5	2.7	2.5	2.4	2.8	2.9
											2.8	3.3	3.3	2.3	2.7	2.9	2.6	2.4	2.8	2.9	2.5	2.1			
											2.4	2.7	2.8	3.1	2.7	2.9	2.8	2.6	2.6	2.4	2.2	3.4			
												2.3	2.7	3.1	2.9	2.9	2.6	2.4	1.9	2.6					
												3.0	2.2	2.6	2.4	2.4	2.6	3.6	3.0	2.4					
												2.2		2.9	2.4	2.9	2.8	3.6	2.7	3.4					
														3.2	2.8	2.9	3.0	3.6	3.5						
														2.3	3.0	2.9	3.0		2.7						
														3.0	2.4	2.5									
																2.9									
Samples																4.0									
3	3	1	2	2	3	3	2	3	3	3	5	8	7	11	11	12	10	9	10	9	5	5	3	3	3
Average																									
4.26	4.33	4.5	4.3	4.6	4.3	4.66	3.9	3.2	3.5	3.1	2.88	2.69	2.84	2.85	2.69	2.73	2.76	2.62	2.43	2.37	2.62	2.68	2.50	2.8	2.96

was reached are probably within the experimental error. The large difference between the total solids and sugar noted during the first stages of ripening is no doubt due to the high acid content of the unripe grapes. The fact that the difference remains fairly constant after the grapes have become mature is to be expected, because the cream of tartar, total acid, and protein remain fairly constant as maturity is approached and during the periods of maturity and over-ripeness.
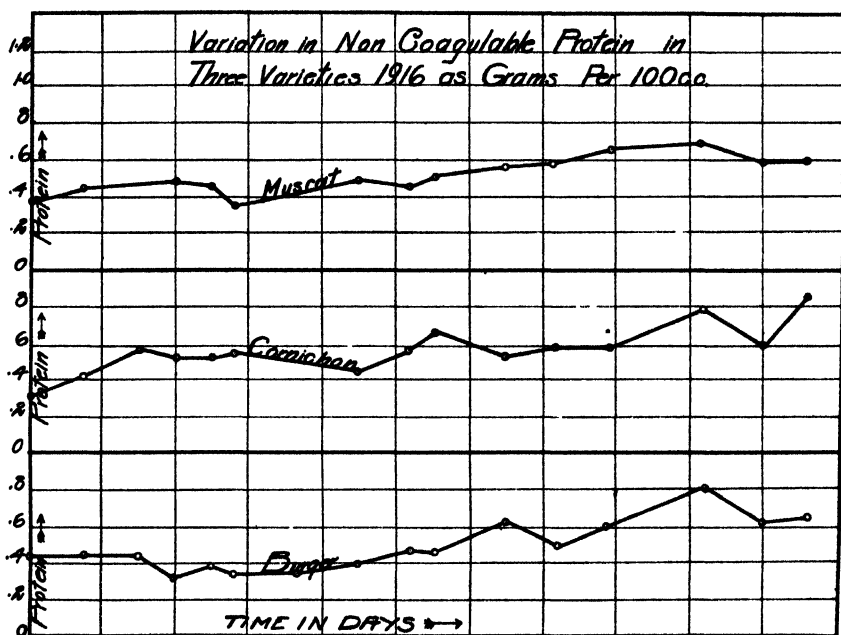
Fig. 11—Variation in non-coagulable protein content for three varieties, 1916.

Protein.—The total nitrogen content of the various samples was multiplied by 6.25 to convert it into its protein equivalent. Owing to the fact that the samples were sterilized by heat and filtered before analysis, the figures represent only the protein not coagulated by heat.

The curves show that there is a slow increase in protein content during g.owth and ripening and the greatest increase occurs during the period of most rapid increase of sugar and most rapid decrease of acid. The increase amounted to about .2 per cent in the case of the Muscat and .6 per cent in the case of the Cornichon. The increase seems to be quite definite, although the protein curves are not so regular as those of total solids, sugar, and total acid.

SUMMARY OF CHANGES IN MUST OF GRAPES DURING GROWTH AND
RIPENING OF BERRIES

1. *Total Solids.*—The total solids remain fairly constant during
the period of growth, corresponding to the period between setting of
the berries and the time at which the berries have reached almost
full size but are still hard and green. From this point on, there is a
rapid increase in total solids due to increase in sugar.

After the period usually considered as full maturity is reached,
the increase in total solids is slow. The question may be raised as to
whether this last increase is due to an actual synthesis and secretion
of sugar or other solids, or simply to evaporation of water. The fact
that there is no change in the curve of the acid decrease at this time
indicates that the same processes are continuing and that the increased
Balling degree represents an actual increase of solids. This view is
fortified by observations regarding the increase of weight of solids
during the ripening of raisin grapes. It has been shown that the
weight of dried grapes shows a continuous increase up to the highest
degree observed, 28.75 Balling.[7]

2. *Sugar.*—The total sugar during the growth period comprises
only a small amount of the total solids. During ripening, the sugar
rapidly increases and then constitutes a much greater proportion.
During ripening, the sugar curve follows the total solids curve closely.
It is more or less the mirror image of the total acid curve multiplied
by five, i.e., increases as the acid decreases.

3. *Total Acid and Free Acid.*—During the early stages of the
growth of the berries, the acidity increases owing to an increase of
free acid. This is a fact that the authors have not found mentioned
in the literature. During ripening, the total and free acid rapidly
decrease. After maturity is reached, the decrease is very slow.

4. *Cream of Tartar.*—There is a very slow, but usually fairly defi-
nite, increase in cream of tartar during ripening. This increase is
very much less than the decrease in free acid, and therefore can not
account for any great part of this decrease.

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[7] Bioletti, Frederic T., Relation of the maturity of the grapes to the quantity and
quality of the raisins. Proc. Inter. Cong. of Viticulture, San Francisco, 1915,
pp. 307–314.

5. *Protein.*—The protein not coagulated by heat increased definitely during growth and ripening, although the increase was not so regular nor so marked as the increase in sugar or the decrease in total acid.

6. *Difference Between Total Solids and Sugar.*—This factor remained constant for the lower percentages of total solids, decreased during the rapid ripening stage, and remained constant through maturity and over-ripeness.

A NEW METHOD OF EXTRACTING THE SOIL SOLUTION

BY

CHAS. B. LIPMAN

A NEW METHOD OF EXTRACTING THE SOIL SOLUTION

(A Preliminary Communication)

BY

CHAS. B. LIPMAN

While studying, in 1914, some of the data obtained by Quincke in measuring the forces by which thin water films are held by tiny particles of solid matter, there occurred to the writer a new possibility for a method of extracting the soil solution from soils with optimum moisture contents. By making a simple calculation, I found that if Quincke's figures were correct, particles of .005 mm. in diameter had the power of holding very thin films of water with a force equivalent to about 300,000 lbs. to the square inch. I argued, therefore, that since particles of .005 mm. diameter constitute the "clay" fraction in some mechanical analysis systems and since a large part of soil material may consist of much larger particles, that it should be possible to bring to bear on soils by pressure apparatus already in existence enough force to separate soil particles from some water, even when soils contained relatively small quantities of moisture. It appeared to me, moreover, that the large machines used in engineering laboratories for testing the strength of materials should be admirably adapted to the task of expressing water from soil if suitable containers for the soil are employed. With this idea as a basis, I started, in the year above mentioned, to experiment first on peat soils with a letter press of the old fashioned sort and found that water could be obtained with it from peat containing 40% of moisture. I then proceeded to have made a special perforated brass plate for the bottom of an iron casing about 12 inches long and about 6 inches in diameter. A quantity of clay adobe soil with optimum moisture content was placed in

the tube, a plate placed over it and pressure applied in a machine of a capacity of 200,000 lbs. to the square inch. About 25 c.c. of liquid were thus obtained from eight pounds of soil. The result of this experiment was unsatisfactory, owing to the small amount of liquid obtained from a soil with an optimum moisture content. I determined, therefore, to use a tube with a much smaller diameter (1 to 2 inches), so that the pressure exerted by the machine could be concentrated on as small a surface as possible and thus rendered more efficient. When such a tube was made, other difficulties were encountered. A few months later, these were surmounted and revised forms of apparatus were thus prepared from time to time as other duties permitted. No form of these was satisfactory even though I had demonstrated that small amounts of the soil solution could be obtained with some of them. During the last few months, however, I have had the privilege of the counsel of Mr. C. T. Wiskocil of the Department of Civil Engineering of this university, who has designed a new form of pressure tube for my purposes. Such a tube was made up and we have tried it out, recently, on several occasions with gratifying results. In the case of a very fine sandy soil containing an optimum moisture percentage (about 15% by weight), nearly two-thirds of the moisture was expressed from samples of 300 to 400 grams of moist soil. In the case of a clay loam soil, we were not so successful, but from two or three samples of about 300 grams each of such a soil containing about 20% of moisture (by weight), we obtained enough of the soil solution to make conductivity measurements and, if needed, quantitative analyses. Certain difficulties were encountered in pressing the clay loam soil, which did not obtain in the case of the fine sand, but these were also surmounted by another suggestion originating with Mr. Wiskocil. Even now we find that our apparatus needs to be changed, or a new one must be made to stand pressure in excess of 50,000 lbs. to the square inch, so that greater efficiency in pressing clay loams and clays may be attained. The detailed description of our apparatus, and of the results of conductivity measurements and analyses of the solutions obtained are reserved for description in another paper in which due credit will be given Mr. Wiskocil and Dr. D. D. Waynick for invaluable assistance rendered in connection with these matters.

My principal object now is to direct the attention of my colleagues in soil investigations to the fact that, after nearly four years of desultory effort, I have succeeded in demonstrating that direct pressure

can be used successfully for purposes of obtaining the soil solution as it exists in relatively thin films around the soil particles. The procedure is rapid, clean, and of high efficiency. With further improvements in apparatus which we are now planning, the method should supplant all other methods known today, including even the Morgan procedure.[1] None of the other methods are really satisfactory and even that of Morgan is laborious and slow, and introduces the factor of oil, which complicates and renders it extremely time-consuming and untidy. Within recent months, I have noted in the literature that attempts have been made by Ramann, März, and Bauer[2] and by Van Zyl[3] to use direct pressure as I have done. The original papers detailing the work of these investigations are not available to me, however, and I am almost entirely in the dark as to the details of the method and, in one case, of the magnitude of the pressures employed. The maximum pressure thus far exerted in my method has been approximately 53,000 lbs. to the square inch, whereas Ramann and his associates with a hydraulic press seem to have used only about 1500 lbs. per square inch. Moreover, if the abstract of their paper which is available to me has interpreted the authors correctly, their method is only applicable to soils made up of very fine particles or containing much organic matter. My experience has always been that the coarsest soils are always the easiest to manage in expressing water from them. Indeed, until recently, the fine grained soils, as above intimated, gave me considerable trouble, because they would creep out of the container in fine ribbons, while the pressure was being applied. Mr. Wiskocil's suggestion of a thin casing of sand for the fine grained loam or clay loam has obviated that difficulty, however. I judge from my experience, moreover, that Ramann and his coworkers must have used very wet soil or they could not possibly have secured solutions from them at the low pressure mentioned. The abstract of Van Zyl's paper says nothing about the pressure used by him and the manner in which it was applied. The statement is that the soil can be "squeezed." Other comparisons of my method with the comparable ones just discussed will be given in a later paper.

Finally, it may not be superfluous to emphasize the importance to all soil studies of the proper use of the method which I have described above. It allows of the direct determination of the concentration of

[1] Soil Science, vol. 3, p. 531 (1917).

[2] Tut. Mitteil. Bodenkunde, vol. 6, p. 27 (1916), cited from Chem. Abst., vol. 11, no. 22, p. 3078 (1917).

[3] Jour. Landw., vol. 64, p. 201 (1916), cited from E. S. R., vol. 36, p. 720.

the soil solution, and of the amounts of each of the solutes contained therein. It renders possible, further, such studies as will clarify our vision with regard to the relations, if any, which obtain between the soil solution and soil extracts as ordinarily made. It permits us for the first time, so far as I am aware, to obtain quickly and directly large portions of the soil solution as it exists naturally under field conditions when crops are growing, and thus to correlate these solutions in all their qualities with the conditions of the growing crop. It may doubtless be the means of throwing much light on the methods for making nutrient solutions for growing plants, and probably also on many obscure problems in plant physiological pathology. Indeed, the possibilities are many in which the method which I have described for obtaining the soil solution can be used to the very great advantage of soil and plant studies.

Transmitted March 8, 1918.

ᴛʜᴇ ᴄʜᴇᴍICAL COMPOSITION OF THE PLANT AS FURTHER PROOF OF THE CLOSE RELA- TION BETWEEN ANTAGONISM AND CELL PERMEABILITY

BY

DEAN DAVID WAYNICK

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THE CHEMICAL COMPOSITION OF THE PLANT AS FURTHER PROOF OF THE CLOSE RELATION BETWEEN ANTAGONISM AND CELL PERMEABILITY

BY

DEAN DAVID WAYNICK

CONTENTS

INTRODUCTION

A solution of a single salt at certain concentrations is toxic to plants grown in it. The addition of a second salt usually permits of growth superior to that in a solution of a single salt alone even though the added salt is toxic when used by itself. A third salt added may permit of a still further increase over the growth in the two salt solution. Other salts added will increase or decrease growth, depending upon the salt used. Qualitative relationships only have been considered. When we adjust the quantitative relationships of the various salts present, having at the same time due regard for their qualitative

nature, we get as a result a solution in which the plant grows and functions normally. Such a solution has been termed by Loeb, "physiologically balanced."

It is evident that if growth is better in a two salt solution the toxic effects of the solution due to a single salt must be lessened by the presence of the second salt. We may refer to either as the second salt since either may be toxic alone. On the addition of a third salt the increase in growth over that obtained in the two salt solution points to a still further lessening of the toxic properties of the various salts present taken singly. This action of one or more salts in limiting or preventing entirely the toxic effects of one or more other salts, is termed antagonism. Sea water may be taken as an example of a physiologically balanced solution or a solution in which the mutual antagonism between the constituents of the solution is such as to allow of normal growth of numerous organisms.

The fact of the existence of antagonism has been proven by a number of investigators working in plant and animal physiology, but the mechanism of antagonistic action is by no means clear. Since salts are very largely ionized in the nutrient solutions usually employed, it is probable that antagonism has to do with ions. Further, antagonism will probably take place between the ions present in, or between, the ionic constituents of the solution, and the living membranes in contact with the solution. Loeb[1] first advanced the theory that one ion may prevent the entrance of another ion into living cells and that in this property lies the reason for antagonistic action. On the basis of this hypothesis, penetration precedes the manifestations of toxic effects and where penetration does not occur, due to antagonistic action, there are no toxic effects evident. Used in this way, the term penetration means simply the entrance of ions in greater number than would normally occur were the plant cells in their natural environment. Experimental evidence as to the correctness of this hypothesis has been furnished by Loeb[2] in a very interesting series of experiments. Osterhout[3] has applied the electrical conductivity method to the measurement of the penetration of ions into plant tissue, while recently Brooks has confirmed Osterhout's results (1) by determining: the diffusion of ions through tissue,[4] (2) by exosmosis,[5] and (3) by the change in the curvature of tissue.[6]

[1] Amer. Jour. Physiol., vol. 6 (1902), p. 411.
[2] Science, n.s., vol. 36, no. 932, p. 637.
[3] *Ibid.*, vol. 35, no. 890, p. 112.
[4] Proc. Nat. Acad., Sci., vol. 2 (1916), p. 569.
[5] Amer. Jour. Bot., vol. 3 (1916), p. 483.

It is evident that these methods are limited in their application and give no idea of the quantitative relationships existing between the ions actually entering the cells. They do show, however, that the permeability of the plant tissue may be greatly altered by salt action and that solutions which permit of normal growth also preserve normal permeability as regards the ions present in the solution.

OBJECT OF THE INVESTIGATION

In a preliminary paper[7] the results obtained from chemical analyses of plants grown in toxic and antagonistic solutions have been reported. These results were of interest and the general method employed seemed to be worthy of a more extended application in the determination of ions absorbed by plants from solutions, of known composition and concentration. From a consideration of the data in the paper referred to above, it was felt that the results obtained in a more extensive investigation would be of importance: (1) from the standpoint of the effect of various salts upon the permeability of the cell tissue of growing plants; (2) from that of the effects of various salts upon the nutrition of plants as evidenced by growth; (3) from that of a possible correlation of growth with the absorption of ions; and (4) from the standpoint of the quantitative relationships existing between certain ions of the solution and the same ionic relationships in the plant.

The various phases of the problem as outlined above will be considered in the discussion of the experimental results following.

REVIEW OF PREVIOUS INVESTIGATIONS

It is not intended that the following review of the previous work done in this field of plant physiology be exhaustive. Robertson[8] has reviewed the literature dealing with antagonistic salt action very completely up to a recent date. Brenchley[9] and Lipman and Gericke[10] have referred to all the important work done with regard to the effects of the salts of the heavy metals upon plants. The present review therefore touches only the work bearing directly upon the

[6] *Ibid.*, p. 562.

[7] Contribution to the causes of antagonism between ions. (Univ. Calif., Master's thesis, 1915.)

[8] Ergeb. Physiol. Jahrb., vol. 10 (1910), p. 216.

[9] Inorganic plant poisons and stimulants. New York, Putnam, 1915 (Cambridge agricultural monographs).

[10] Univ. Calif. Publ. Agr. Sci., vol. 1 (1917), p. 495.

present problem or work so recent as not to be included in the papers cited above.

A large share of the contribution to the experimental evidence in regard to antagonism between salts as regards plants we owe to Oster-hout. In a series of papers he has shown that any salt may be toxic to plants when used alone in solution at certain concentrations and further that the addition of a second salt may, in proper concentration, modify or eliminate entirely the toxic effect of the first salt. He has shown further that acids, alkalies, and various organic compounds may likewise be toxic to plants and that their toxic effects may be modified by the presence of a variety of compounds, depending upon the toxic substance employed. By measuring the resistance of cylinders of Laminaria in solutions of one salt and in solutions containing two or more salts, he has brought forward much evidence as to the penetration of ions into plant cells. While this method has yielded very valuable results both as to the rate of entrance of ions and also the total number of ions penetrating, it does not yield results which give us a knowledge of the relative amounts of the various ions which penetrate the tissue when the qualitative as well as the quantitative relationships of the nutrient solution are varied. Osterhout has shown, however, that penetration is more rapid, and the degree of permeability is greatly increased, in unbalanced solutions and further that as the permeability of the plant tissue more nearly approaches normal the growth of the plant is also more nearly normal.

Szucs[11] has used *Cucurbita pepo* as an indicator by immersing the young seedlings in various solutions for varying periods of time and counting those still able to show geotropic movement when placed in a horizontal position in a moist chamber. He found a marked antagonism between copper sulphate and aluminum chloride and concludes from his experiments that antagonism consists in the mutual hindrance of similarly charged ions in entering the cell. He states further that the rate of absorption of equally charged ions is of great importance. His chemical methods are open to question, for in the experiments reported the test for copper used was that of boiling the roots and testing the resulting solution for copper with hydrogen sulphide.

By analyzing the solution in which pea seedlings had grown, Pantelli[12] has determined ion absorption. The growing period was short.

[11] Jahrb. Wiss. Bot. (Pringheim), vol. 52, no. 1 (1912), p. 85.
[12] *Ibid.*, p. 211.

He found a rapid absorption of zinc, manganese, iron, and aluminum, but the total amounts taken up were small. He gives other evidence of the selective absorption of various other ions from solutions, but these results are of not direct application here. It is of interest to note, however, that he found a direct relation between time and ion absorption. His most important conclusion, which bears directly upon the problem in hand, is that strong narcosis was associated with the penetration of ions in large numbers.

Schreiner and Skinner,[13] using a similar method, have determined the amounts of phosphoric acid, nitrates, and potassium remaining in a solution in which plants had been grown. Various ratios of these three ions were employed, the total concentration being 80 parts per million. They found widely varying amounts of these three ions removed from the solution, and further there seemed to be a possible difference of 20 to 30 per cent in the removal of any one without an apparent effect upon the growth of the plants. Under the conditions reported by them increased growth was correlated with increased absorption.

By means of conductivity measurements of solutions in which pea seedlings were growing, True and Bartlett[14, 15, 16] have determined the rate of absorption and of excretion of electrolytes. Their work was done with one, two and three salt solutions. In general they found a greater absorption when a mixture of salts was present than when single salts were used. Further, the absorption relationships of salts with a common kation seem to be similar. For example, from solutions of low concentrations, potassium chloride, potassium sulphate, and potassium nitrate are not removed, but on the other hand there is an excretion of electrolytes by the plant. In direct contrast, calcium nitrate and calcium sulphate are removed from their solutions in every concentration employed and no excretion of electrolytes from the plants could be detected. It seems probable that the low concentration employed by them acted as a limiting factor in some cases.

In a recent paper Breazeale[17] has shown that the presence of sodium carbonate, and sodium sulphate, when used in concentrations of 1000 parts per million in nutrient solutions, decreased the absorp-

13 Bot. Gaz., vol. 50 (1910), p. 1.

14 Amer. Jour. Bot., vol. 2 (1915), p. 255.

15 *Ibid.*, p. 311.

16 *Ibid.*, vol. 3 (1915), p. 47.

17 Jour. Agr. Research, vol. 7 (1916), p. 407.

tion of potassium and phosphoric acid as much as 70 per cent below that of the control cultures.

The work of Gile[18] is of interest in this connection. From ash analyses obtained in investigating the cause of chlorosis in pineapples, he found a direct relationship between the absorption of lime and that of iron; that is, when the absorption of lime was high but little iron was taken up. In soil studies Gile and Ageton[19] found no direct relation between the lime content of plants and varying amounts of lime and magnesia in the soil.

A few investigations have been made on the absorption of specific elements from solution, but these need only be mentioned in the present connection. Maquenne[20] found that mercuric chloride causes marked increase in permeability of the protoplasm, although it is not necessarily absorbed itself in any considerable quantities. Marsh[21] correlates the amount of barium chloride present in the soil with that found in the plant. Colin and De Rufz[22] always found absorbed barium localized in the roots.

A large number of analyses of plants grown under various conditions have been reported, but the environmental factors have varied so greatly as to render the results obtained of little value in the present study.

From this review it is evident that no quantitative study of the elements actually absorbed from the nutrient solutions, balanced and unbalanced, has been made with the idea in mind of a correlation between the absorption of the various ions with their antagonistic or toxic effects in solution cultures.

METHODS

Barley was used as the plant indicator. The seeds were obtained from the University Farm at Davis and were of a pure strain of the Beldi variety. The method of sprouting the seeds, while simple, has not been noted elsewhere and has given such excellent results, both to the writer and to others, that it seems worthy of mention here in detail. A piece of oilcloth about 12 x 18 inches was covered with several thicknesses of paper toweling and the whole thoroughly wetted.

[18] Porto Rico Exp. Sta. Bull., 11 (1911).

[19] *Ibid.*, Bull. 16 (1914).

[20] C.-R. Acad. Sci. (Paris), vol. 123 (1896), p. 898.

[21] Bot. Gaz., vol. 54 (1912), p. 250.

[22] C.-R. Acad. Sci. (Paris), vol. 150 (1910), p. 1074.

Selected seeds were distributed over the toweling so that about two hundred were placed on an area of the size indicated above. Another layer, made up of several sheets of toweling, was then laid on the seeds and the whole thoroughly soaked with water. The water was allowed to evaporate gradually until the paper was but slightly moist to the touch and the water relation then maintained constant until the seedlings were transferred to the solutions. If the paper is kept too moist the growth of molds is often very abundant, but with a low moisture content no trouble was experienced from this source. By the time the roots were a quarter of an inch long, the upper layer of paper was supported two or three inches above the seedlings. This procedure permits of a straight growth of the shoots, which is of considerable importance in placing the seedlings in the corks. The seedlings were transferred when the shoots were about an inch and a half in length. The paper in which the roots are grown, tears apart readily without injuring them in any way, the oilcloth not permitting their downward penetration. There is no contact with metal containers at any time, the apparatus required is practically nothing, the time period is short—about six days under greenhouse conditions—and strong seedlings are obtained which can be transferred to any containers without injury.

The containers used were quart jars of the Mason type, each holding approximately 950 c.c. of solution. The inside of each jar, as well as that of the bottles for the stock solutions, was coated with a layer of paraffin so that the solutions were never in contact with the glass. The outside of the jar was covered with black paper to exclude light, the black surface facing the glass. Flat corks, having a diameter of three and a half inches, were used to support the seedlings. Each cork had seven holes, one in the center through which distilled water was added to maintain the volume of the solution as nearly constant as possible, and six equally spaced, one and a quarter inches from the center, for holding the seedlings. After the holes were made the corks were soaked in boiling paraffin.

To introduce the seedlings the corks were turned upside down, supported by the rim of the jar, and the shoots stuck through the holes prepared for them and held in place by a small piece of cotton. On turning the corks over the seedlings were in their proper position without being in the least injured, for there was no necessity for touching the roots at any stage since the plant was always picked up by the seed coat. The method suggested by Tottingham[21] was tried,

but the one outlined above proved very satisfactory and much simpler.

The basic nutrient solution used throughout was Shive's three salt nutrient[24] containing the following salts in the given partial molecular concentrations:

$$K\ H_2\ PO_4 \quad \text{...............} \quad \text{...............} \quad .0180\ M.$$
$$Ca\ (NO_3)_2 \quad \text{...} \quad .0052\ M.$$
$$MgSO_4 \quad \text{..} \quad .0150\ M.$$

. The stock solution was made up to twice the strength indicated above and diluted as necessary by the addition of added salt solution, or distilled water, or both.

In the case of the chlorides used, viz., calcium, magnesium and potassium, normal or twice normal solutions were prepared and standardized by titrating against a standard silver nitrate solution. Normal solutions of magnesium and potassium sulphate were standardized by weighing the barium sulphate precipitate. Solutions of copper, zinc, iron, and mercury salts were prepared in concentrations of 1000 parts per million by weighing out the carefully dried salts.

The final volume of solution required for the duplicate jars was approximately two thousand cubic centimenters. Starting with a thousand of the nutrient solution, various volumes of the standard solutions were added so that when the total volume was made up to two liters with distilled water, the concentrations of the various salts would be those reported in the accompanying tables.

The growing period was six weeks. The duplicate cultures were grown in specially constructed mouse-proof cages each holding ninety jars. The tops of the cages were open and the sides made of coarse wire screening. The different parts of the cages were equally well lighted, as shown by the nearly equal growth of the controls in different parts of the cages. When necessary the plants were supported by cords strung across from side to side of the cages.

The solutions were not changed during the growing period, but the volumes were kept as nearly constant as possible by adding distilled water. There are objections to this method, as there are objections to the method of using water cultures at all. The growth was found to be very satisfactory and compares favorably with the growth

[23] Physiol. Researches, no. 4 (1915), p. 174.
[24] Amer. Jour. Bot., vol. 2 (1915), p. 157.

obtained by other investigators in comparable periods of time. A further discussion of this point will be taken up below.

At the expiration of the six weeks growing period the plants were removed from the corks, the roots rinsed thoroughly with distilled water, placed between layers of paper toweling, dried in the oven at 100°–105°C, roots and tops separated, weighed, and placed in envelopes ready for analysis. For analysis the roots from duplicate cultures were combined unless the dry weight was sufficient to allow of separate analysis.

Total ash was determined after direct ignition of the dry material in a muffle at a low red heat until no trace of carbon remained. The ash was then taken up in dilute hydrochloric acid and evaporated to dryness to remove possible contamination with silica. Iron was precipitated as the hydroxide with ammonia and titrated with $\frac{N}{100}$ potassium permanganate after reduction with zinc and sulphuric acid. This determination was made because of the relation Gile has shown to exist between calcium and iron absorption by plants. Calcium was precipitated as oxalate and titrated with $\frac{N}{100}$ potassium permanganate. The double precipitation of the oxalate assured freedom from magnesium contamination. Magnesium was precipitated by ammonium phosphate and weighed as the pyrophosphate. Potassium, where determined, was precipitated and weighed as the chloroplatinate. Copper was determined colorometrically by using the ferrocyanide method. The amount of material available precluded the possibility of a more complete analysis than was made if any degree of accuracy was desired. For example, in Series VII, the weight of the ash varied from 12 to 233 milligrams in the case of the roots and from 32 to 183 milligrams in the case of the tops. While these variations are not extreme, they are fairly representative. The values of these elements actually determined cannot be taken as absolute in every case because of the limited amounts of material available, but the significant differences are so great as to make a small variation in this regard of minor importance.

The strength of all solutions is uniformly expressed in terms of molecular concentrations since this mode of expression has been quite generally used in experimental work reported by different investigators.

Under experimental results twenty-six series are reported. A series, as used in the present work, may be defined as a number of

duplicate cultures containing one salt in varying concentrations in each, or one salt constant and varying concentrations of a second salt. In some instances both salts varied but only in concentration, the same ratios being maintained. These are few. The number of concentrations reported vary from three to fourteen in a series, depending upon the salt used. Before two salts were taken together, the effects of each separately upon the plants were determined. Usually this meant only the establishment of the toxic limits of the salts employed when used in the nutrient solution. Several series of this kind are not reported here, as no analytical work was done upon them.

Calcium and magnesium salts were used to a large extent because of the fact that their kations can be determined with less experimental error than most other nutrient salts where the small amounts of material dealt with here are considered; also it was of interest to determine whether or not there is a lime-magnesia ratio for plants grown under carefully controlled conditions. Copper, zinc, iron, and mercury salts were used because of the fact that their toxic and antagonistic effects have not been previously determined as regards absorption. Potassium chloride was the only monovalent salt used.

A longer growing period than has usually been employed was considered important. McGowan,[25] in conducting experiments in pure solutions of sodium, potassium and calcium chlorides, found growth better in the first two at the end of six days, but far superior in a solution of calcium chloride in twenty-five days. In a qualitative way the same relationships were observed in the present investigation. It seems reasonable to assume that the results obtained in six weeks with plants are more nearly representative of the true effect of various solutions than those obtained in two or three day periods or even in three week periods. But it is not assumed that the results herein reported are the same as those which might be obtained were the plants grown to maturity. It is hoped that more data may be presented shortly on this point.

In the following section, in which the experimental results are given, the time factor and the basic nutrient solutions are constants.

EXPERIMENTAL DATA

All analyses are reported as percentages of the dry weights of the plants. To make the results obtained as clear as possible, graphs and photographs have been used throughout as well as the tables giving the actual percentage composition of the plants.

[25] Bot. Gaz, vol. 45 (1908), p. 45.

The relationships of calcium to magnesium salts are reported in the first seven tables. For a review of the more important literature bearing directly upon the relationships of the salts to these two elements reference is made to McCool,[26] who has considered these in some detail, and to a recent critical survey of the lime-magnesia ratio hypothesis by Lipman.[27]

As is evident from table 1, calcium chloride does not become toxic until present in concentration of over .24 M. Up to and including this concentration the growth seems to be but little affected by the increasing concentrations of the salt added. The percentage of calcium in the plants shows no direct increase with increasing concentration of calcium chloride in the solution. The lowest percentage of calcium given occurs in a concentration of .20 M. calcium chloride.

In table 2 there is a close parallelism between the growth of roots and tops. Two low points on the dry weight graph are evident, the first occurring at cultures 4 and 5 and the second from 7 to 11. At these low points we have a high percentage of magnesium in both roots and tops, but of calcium only in the second low point. Calcium is low where growth is good in cultures 2 and 3. But the most interesting feature is the decreased absorption of both elements at culture 6, where there is a distinct increase in dry weight. Iron was not present in sufficient concentration to allow of titration until culture 11 is reached. It may be stated here that the iron determined is limited to that in the seed as a maximum, for it was purposely excluded from the solutions except where its toxic or antagonistic action was under observation. In many instances the titration of this residual iron is of interest.

Table 3 is a record of one of the most interesting and significant series reported. The root growth was so limited in nearly every culture that no attempt was made to segregate roots from tops for separate determinations except where the total dry weight was so greatly increased as in cultures 6 and 11. In the first place we have double maxima of growth, the first in culture 6 and the second in 11. The total dry weight at culture 11 is twice that at 6, but the dry weight in culture 6 amounts to a 35 per cent increase over that in culture 7. A direct inverse relationship is shown between total growth and absorption at these two high points; the maximum growth in culture 11 is accompanied by the lowest absorption of calcium and magnesium. The percentage of magnesium is low in culture 6, but that of calcium

26 Cornell Univ. Agr. Exp. Sta. Mem. 2 (1913), p. 127.
27 Plant world, vol. 19 (1916), p. 83.

is higher than in the cultures of slightly higher or lower concentrations. No explanation of the narrow ratio between these two elements at this point can be offered. It is of interest to note the very great increase in the amounts of calcium and magnesium found in the plants grown in concentrations of .20 M. calcium chloride alone. While magnesium chloride is constant throughout the series, the amount of magnesium does not increase proportionately to that of calcium.

A still higher concentration of magnesium chloride was used in the series reported in table 4. The percentage of magnesium found in the roots is very high and would indicate that it was not entirely removed from the roots by washing. In general the percentages of calcium and magnesium found are high, the calcium content increasing as the concentration of calcium chloride present in the culture, but not proportionately. Magnesium is lower at the greater dry weights for the tops, the decrease amounting to 50 per cent in the case of culture 6.

Magnesium sulphate was used alone in the series reported in table 5. The decrease in growth is nearly proportional to the increase in concentration of the added salt. In this series we have a very marked decrease in the percentages of calcium and magnesium present in the roots without any evident effect upon the growth of the plants, especially that of the tops. Here again, however, we have increased absorption of calcium as the percentage of magnesium increases, even though the concentration of the former in the nutrient solution is constant. It is of interest to note that the percentages of both elements in the tops throughout this series are low and vary but little, regardless of the increasing concentration of the nutrient solution.

Very marked antagonism between calcium chloride and magnesium sulphate is shown in table 6. The dry weight of the plants grown in a solution of magnesium sulphate .18 M. concentration was .29 gram, but when .04 M. concentration of calcium chloride was added the average dry weight was 1.20 grams and in a concentration of .18 M. magnesium sulphate and .24 M. calcium chloride the average dry weight was .98 gram. Between these two concentrations of calcium chloride the dry weights recorded are uniformly high. Correlated with the rapid decrease in growth, in concentrations of .24 M. of calcium chloride, is the marked increase in the percentage of both calcium and magnesium found in the plants. The graphs representing the amounts of these elements found crosses the growth graph coincident

with its sharp decline. The low percentage of magnesium is of interest since the concentration of the culture solution was uniformly high with respect to this ion.   .

It is striking that there is a marked decrease in the growth of roots at the concentration which gave the best growth of tops, and further that the percentage of calcium in the tops and magnesium in the roots parallel this decrease in the growth of the roots. A comparison of the results obtained with magnesium sulphate as against those with magnesium chloride is reserved for later discussion.

In table 7 we have an opportunity to compare indirectly anion effects, or possibly the effects of combinations of the same kation with different anions. From preliminary results it seemed advisable to use .15 M. magnesium sulphate in this series instead of .18 M. as used in the preceding series, so that the concentration of magnesium ion is not equivalent in the two series. A solution containing magnesium sulphate .15 M. plus calcium nitrate .08 M. proved highly toxic, while a solution containing calcium chloride of the same concentration as the nitrate in the above solution supported normal growth. It is possible that the difference is due to the toxic action of the nitrate ion on the plant directly. Tottingham has shown that the total ionization of a nutrient solution was decreased 10 per cent below the theoretical by the addition of calcium nitrate in low concentrations. It is possible that the ionization of some other salt is repressed so that there is an actual lack of some ion necessary for growth. The percentage of calcium found was not high enough in any case to account for the toxic effects shown. Magnesium was found in extremely large amounts, 9.20 per cent in the case of culture 6, the largest percentage recorded in any culture studied. Unfortunately the series in which the toxic effects of calcium nitrate alone were studied was lost, so it cannot be reported here.

Potassium chloride was the only monovalent salt studied, and the results are given in tables 8 and 9. The growth shown in the various concentrations of potassium chloride used was approximately the same as that found when magnesium sulphate was used alone. The increase in the percentage of ash, as far as the tops are concerned in table 8 is very striking. The percentage of calcium found in the tops and of magnesium found in the roots remains practically constant throughout. The amount of potassium absorbed increases as the concentration of potassium chloride in the solution increases and inversely as the growth of the plants. The toxic effects due to the

addition of potassium chloride to the solution are much more evident in the tops than in the roots with respect to the increasing concentrations of potassium chloride.

Using a constant concentration of potassium chloride of .18 M., which is an increase of .02 M. over the highest concentration of that salt reported in table 8, against varying concentrations of magnesium sulphate, the results reported in table 9 were obtained. There is a marked increase in total ash as the concentration of the nutrient solution with respect to magnesium sulphate increases. Parallel with this increase is the higher percentage of potassium. The growth decreases inversely. Antagonism between the two salts is evident where the lower concentrations of magnesium sulphate were used. In cultures 2 and 4 of this series, we have a marked increase in growth over that of culture 3. Absorption is markedly lower at the two high points than at the intermediate concentration, where the solution is evidently more toxic. The least growth obtained in the series was recorded in culture 7, which shows the highest absorption of all the elements determined. In the two higher concentrations of magnesium sulphate used the growth was increased somewhat while the percentage of calcium, magnesium, and potassium in the plants decreased markedly. It seems worthy of note that the amount of iron in the ash was not sufficient to allow of titration at any concentration employed in the series. This series very well illustrates the point which has been brought out a number of times before of the relationship between absorption and growth. Here we have five cultures in the one series of which this relationship is evident. The relations are not absolute in every instance, but there can be no doubt whatever of the tendency toward decreased absorption as growth increases, or that antagonism between ions results in decreased absorption of at least some of the ions present in the nutrient solution.

We turn now to a consideration of the effects of a few of the salts of the heavy metals upon growth and absorption. In table 10 the effects of adding various concentrations of aluminum chloride are shown. Growth is decreased in every concentration of the salt used. The high percentage of magnesium is marked in both roots and tops. On the other hand, the percentage of calcium is increased relatively little. The percentage of iron found was practically constant and in total quantity is in marked contrast to the last series considered in which the amount was so small that it could not be determined.

In a solution of .20 M. calcium chloride, the results with the vary-

ing concentrations of aluminum chloride are shown in table 11. In general the toxic effects of the two salts seem to be *additive,* that is, the growth in this series in which two salts are present together is less than in the preceding series where aluminum chloride was used alone. The decrease is not great from the standpoint of total weight, but proportionately is very considerable, amounting to from 33 per cent to 100 per cent in the various concentrations employed. The percentage of magnesium in the two series is about the same. The amount of calcium absorbed, on the other hand, is increased over 300 per cent and remains constant throughout. The total absorption with respect to calcium and magnesium, at least, is uniformly high. This fact is reflected in the increase in the percentage of ash over that of the control. In the next series all factors are the same except that magnesium chloride was used instead of calcium chloride, there being no difference whatever in partial or total concentration. The antagonism shown between magnesium chloride and aluminum chloride in culture 4 is very marked, and correlated with the increased growth is the marked decrease in the percentage of both magnesium and calcium found in tops and roots. The percentage of magnesium found in the plants is not proportional to the concentration in the solution as was true with calcium chloride. An interesting case of the increased absorption of one element with a decrease in the other is well illustrated in the case of culture 6 of this series. Such a relationship has been noted previously, but is apparently of no direct importance from the standpoint of growth.

Ferric chloride, a second trivalent salt, was used in the nutrient solution in the concentration shown in table 13. In the concentration employed, growth is nearly normal and absorption is very nearly the same as with plants in the control cultures, except in the case of calcium. The decrease in some instances in the percentage of calcium found, as iron increases in the nutrient solution, is notable, and will be referred to later in connection with the action of ferric and zinc sulphates.

The effects of adding .20 M. calcium chloride, together with various concentrations of ferric chloride, are given in table 14. The growth of roots and top parallel each other closely. Marked toxic effects are evident in certain combinations as in cultures 3 and 7. The percentage of calcium found in both roots and tops is high in plants grown in the same cultures. The magnesium present in the tops shows the same relationships as the calcium, although the

amount absorbed varies but little from that of the control.   In the roots magnesium is present in large amount when growth is low in culture 2, but in succeeding cultures the percentage found falls off sharply and remains abnormally low without any relation to growth or concentration of the solution.   The percentage of iron is high in cultures 6 and 7, in which the weight of the plants was small.

Substituting magnesium chloride in equivalent concentration for the calcium chloride used in the preceding series, the results are of a very different order from those in table 15.   The absolute growth of the tops is greater than in series 14.   Root growth does not parallel the growth of the tops.   The toxicity of the solution is scarcely evident at some concentrations while markedly increased at others.   Absorption, with the exception of the magnesium in the roots, is usually low, amounting to about that of the control, but the percentages of calcium and magnesium found bear no apparent relation to the differences in growth.   Iron, however, shows the inverse relation already noted in many other series with calcium and magnesium, that is, high percentage present when growth is low, and vice versa.   The toxic and antagonistic effects as well may be due in this instance to the ferric ion, but this statement is by no means indisputable.

In several tables following, the effects of copper salts are given. Previously copper salts have been shown to be highly toxic to plants as well as to a wide variety of vegetative forms.   That they may also be stimulating has been shown recently by Forbes[28] using solution cultures, and by Lipman and Gericke[29] in soil cultures.   The reader is referred to the latter paper for an extensive review of the subject.

The results with copper chloride are reported in table 16.   Growth, especially that of the roots, was limited in every concentration reported.   In fact, the growth of the roots was so limited that their weights are not given.   There is a suggestion of antagonistic action between the nutrient solution and copper chloride in cultures 3 and 5. The percentage of magnesium found is high where growth is low. The same is not true of calcium, the percentage of which is low and decreases as growth decreases to a certain extent.   A trace of copper was found in every case and appreciable amounts had penetrated the plant tissue at the two higher concentrations.   When ferric chloride is added together with copper chloride marked antagonism is shown.   Table 17 will make this effect evident.   In this series, as in

28 Univ. Calif. Publ. Agr. Sci., vol. 1 (1917), p. 395.
29 *Ibid.*, p. 495.

several following, the concentrations of both salts added increase, that is, both increasing but bearing the same ratio between the two. There is an increase of approximately 100 per cent in the dry weight of culture 2 over cultures 1 and 3. The low absorption of culture 2 as related to 1 and 3 is evident. There is a marked decrease in the percentages of calcium and magnesium found in the plants grown in culture 5, in which the dry weight of the plants was also low. At this second point, however, iron and copper were found in larger amounts than at any other concentration used. As in the previous series the percentage of calcium in the tops does not seem to parallel that in the roots or of magnesium in either roots or tops. A similar relationship was brought out in the previous series in which copper chloride alone was used. No apparent precipitation took place upon the addition of iron in the concentrations given, but a precipitate composed of ferric phosphate was present at the time of harvesting. It is possible that double salts of copper or iron with calcium or magnesium and, for instance, the phosphate ion were formed at the higher concentrations. Their complexes may not be taken up by the plants and hence actual starvation as far as these elements are concerned, may be responsible for the low amounts found in the plants. Such a condition contrasts directly with one in which there is low permeability due to antagonistic effects between the ions in the solution.

In table 18 mercuric chloride was used with copper chloride, since it was desired to determine the effects produced by the addition of two highly toxic salts to the nutrient solution. The results with mercuric chloride alone are given in table 26. They are somewhat irregular, but there can be no doubt of the correlation between the quantitative presence of calcium and magnesium in the tops, of magnesium in the roots, and growth. There is evidence of a distinct antagonistic action between copper and mercuric chlorides both from the standpoint of growth and that of absorption. The root growth was very limited. The percentage of calcium and magnesium in the roots was very high; high enough to account for the decreased growth by itself if we use the results of other series in interpreting this one. Not enough iron was present in any culture to permit of its determination.

Considering the most common salt of copper used in solution cultures and soil work, the results as given in table 19 are especially noteworthy. The concentrations of the sulphate used are low. Distinct evidence of the toxic effects of the salt, together with only slight decrease in growth in culture 4 of the series is shown. High percent-

ages of calcium and magnesium accompany low growth; low percentages of calcium and magnesium go with much increased growth. No iron could be quantitatively determined in cultures 8 and 9. The copper content shows no variations which may be regarded as important, in fact the amount taken up by the plants is somewhat lower where decreased growth is shown.

Zinc sulphate was used with copper sulphate as shown in table 20. There is little evidence of antagonism between the two salts. At the same time there is evidently no direct relationship between concentration and toxic effect, since growth does not decrease regularly with increasing concentration. While the percentages of calcium and magnesium found are somewhat irregular, they increase rapidly as growth becomes less. The percentage of magnesium found in the tops in culture 8 was 1.10 per cent, and in the roots 1.91 per cent. This occurred with the same concentration of the magnesium ion in the nutrient as in culture 1. The percentage of copper found in the dry matter is distinctly larger than that found in the preceding series, in which copper sulphate alone was used.

Copper sulphate used with ferric sulphate shows no evidence of antagonism between the two if the growth of the tops alone is considered, but with the roots there is a marked increase in growth in cultures 3 and 4 of the series. The percentages of magnesium found in the roots is low and constant, which contrasts markedly with the amounts determined in the previous series. The calcium likewise varies but little in the tops and its percentage remains low. On the other hand, the percentages of calcium in the tops and magnesium in the roots show marked increases as growth decreases. The amount of iron remains very uniform until the last culture of the series is reached, when a marked increase is recorded. It will be noted that the percentage of calcium decreases to nearly one-third of the original in the same culture. This relation has been noted previously in other series.

The stimulation resulting from the addition of ferric sulphate to the nutrient solution in the concentrations given in table 22 is remarkable, a total dry weight of 3.9016 grams for the tops of six plants being recorded. The growth of the roots does not parallel that of the tops. In the highest concentration of ferric sulphate employed, the root growth decreased while the growth of the tops was increased. Attention has already been called to cases of this kind in which there may be an increase in the growth of tops with a decrease in

the root growth, or vice versa. As will be noted, the percentages of calcium and magnesium found are low, in fact below the control in every case. Whether or not ferric sulphate would be stimulating in still higher concentrations is not known, but it is probable that the limit of stimulation was reached, since the roots show a marked decrease in growth in the highest concentration used. The percentage of iron found is comparatively high. The reason for this increased growth is evidently bound up with the presence of the ferric salt, but no idea of the nature of its action can be given. It is very evident from the present data, however, that the amounts of the elements present in the plants were low.

In table 23 the results with zinc sulphate alone are reported. There is no stimulation or no antagonism between zinc sulphate and the other constituents of the solution evident in any concentration. As growth decreases magnesium was found present in larger amounts than in the cultures in which growth was more nearly normal. The percentage of calcium remains very much the same in the tops and decreases rapidly in the roots with decreasing growth. Here we have a suggestion of a relationship between zinc and calcium as has already been referred to in the case of iron. It can only be stated, however, that the results as regards calcium penetration are exceptional in the light of the results in other series previously referred to.

Turning to table 24, in which the results with zinc sulphate and ferric sulphate are given, there is a marked contrast on the one hand with series 20 in which zinc sulphate and copper sulphate were used, and on the other hand with the preceding series in which zinc sulphate alone was used. In this series there is marked antagonism shown between the salts employed. This is true for both tops and roots, but the most marked increase in both does not occur in the same culture. The marked increase in growth of the tops evident in culture 4 is accompanied by a decrease in the percentages of calcium and magnesium present in the tops but not in the roots. The percentage of magnesium in the roots increases with decreased growth throughout the series. The calcium in the tops is low and abnormally so in the roots. Growth is good throughout the series and in culture 4 is increased about 50 per cent above the control. This result would hardly be expected from the decreases recorded where zinc sulphate was used alone in the preceding series. The percentage of iron varies somewhat, but does not increase or decrease with any regularity in any one direction. Attention is again called to the low calcium content, especially of the roots.

Little can be said of the mercuric chloride ferric sulphate series given in table 25. Growth is uniformly low throughout, with considerable variation between duplicate cultures. The percentage of magnesium is very high in the roots and while less in the tops, is much above that of the control. The percentage of calcium is uniformly low in both tops and roots. Attention is called to the fact that no iron could be determined quantitatively, except in the highest concentration of salts used. This condition is striking when the rather large amounts of ferric sulphate in the solution are considered.

A short series is reported in table 26 in which the toxic effects of mercuric chloride when used alone, are evident. There is a decrease in growth with increasing concentration of the added salt and also an increasing percentage of both calcium and magnesium found. The very low ash content given by the plants in this series is of interest and will be discussed below.

External Appearances of the Plants

It seems worth while to note here a few of the more striking appearances of the plants. Since iron salts were purposely excluded from all solutions except those in which it was planned to study their effects, the control plants were of a more or less yellowish green color. Aside from this no differences were noted between control plants grown with or without the addition of a little ferric phosphate to the nutrient.

In every series in which growth was limited by the presence of magnesium salts the roots were short and much thickened. With a high concentration of magnesium in a balanced solution, this effect was not noted however. High concentrations of magnesium were also apparent from the decided yellowing of the older leaves. Excessive amounts of calcium were characterized by the appearance of brown spots or streaks on the leaves.[30]

When any considerable growth was permitted the plants grown in solutions of copper salts were dark green in color.[31] Where growth was good the roots were apparently normal. In several of the higher concentrations used, copper hydroxide was deposited upon the roots, especially about the tips. A suggestion is made that possibly copper may replace iron as a catalyzer in connection with the building or activation of chlorophyll.

[30] Jost, Plant physiology (Oxford, Clarendon Press, 1907), p. 85.
[31] Univ. Calif. Agr. Sci., vol. 1 (1917), pp. 495–588.

Several cultures in which mercuric chloride was used and in which growth was good, displayed the same dark green color as noted for copper salts and the same suggestion as made for the functioning of copper in this color relationship may hold for mercuric salts as well in very dilute solutions.

The color was light green when iron salts were present; with the other salts used no marked external effects were noted.

GENERAL REVIEW OF EXPERIMENTAL RESULTS

It seems advisable to consider the results reported in the previous tables together, so that the data presented in one table may be more closely correlated with those given in another. It is proposed to do this in the present section and further to discuss briefly the more important relationships shown.

It will be noted in the accompanying tables that there is considerable variation between the controls grown at different seasons of the year. This was to be expected, since conditions in the greenhouse varied between the different growing periods. For this reason it is not possible to compare one series of cultures with another so far as absolute weights of the dry matter are concerned. Within any one series or between series grown at the same time the absolute weights are comparable. This point must be borne in mind in considering the results as a whole. In some cultures, however, growth was stimulated to such an extent as to far surpass any variation between series due to differing external conditions. Such a case is that of series 22, in which ferric sulphate was added to the nutrient solution in varying amounts. In culture 5 of this series, the dry weight was over twice that of any control plants grown during the entire time.

The experimental work with the salts of calcium plus magnesium was rather extensive. McCool[12] has reviewed the previous work with calcium and magnesium salts as related to plants, so a discussion of that phase of the relationships between the two need not be entered into here. In his own work McCool found that calcium chloride was effective in antagonizing the poisonous effects of magnesium chloride and magnesium sulphate. He found a slight increase in the growth of pea seedlings over the controls based upon the green weight of the plants. This was the case in distilled water and in nutrient solution. It seems probable that the nutrient solution used by McCool was not

32 Cornell Univ. Agr. Exp. Sta. Mem. 2 (1913), p. 129.

a balanced solution, since the addition of either magnesium or calcium chloride resulted in an increased growth of the pea seedlings.

In the present investigation there are only two cases in which the growth of the plants was greater with both calcium and magnesium chlorides present than when calcium chloride was used alone in various concentrations, one in culture 6, series 2, the other in culture 11, series 3. In the latter culture the dry weight of the plants was twice that in the same concentration of calcium chloride alone. There are marked differences in growth recorded between different combinations and concentrations of the two salts, and as can be easily seen from the graphs, the percentages of the two ions found in the plants show an inverse relation to growth in nearly every instance. Proceeding from series to series, the amount of magnesium found in the plants increases with the concentration of the magnesium chloride in the nutrient solution.

Magnesium sulphate is not as toxic as magnesium chloride in equivalent concentrations of the kation. Growth in solutions of magnesium sulphate plus calcium chloride was superior in every case to that found when the salts were used separately. There is a marked contrast between calcium chloride and calcium nitrate in antagonizing the toxic effects of magnesium sulphate, the nitrate proving less effective than the chloride in concentrations of .12 M. and over. This is of especial interest, since the qualitative ionic relations of the nutrient are not altered. It is possible that we are dealing with the effects of undissociated molecules in the higher concentrations, which may be very different from ionic effects.

RESULTS WITH SALTS OF THE HEAVY METALS

Since salts of aluminum, copper, zinc, iron and mercury were used, it will be necessary for the sake of clearness to treat each more or less separately.

Miyake[33] has shown aluminum chloride to be highly toxic, in concentrations above $\frac{N}{7500}$, to rice seedlings grown in water cultures. Similar results have been reported by House[34] and Gies, Micheels and De Heen,[35] Duggar,[36] and Ruprecht,[37] working with several aluminum

[33] Jour. Biol. Chem., vol. 25 (1916), p. 23.
[34] Amer. Jour. Physiol., vol. 15 (1905), p. 19.
[35] Bull. Acad. Roy. Belg. (1905), p. 520.
[36] Plant Physiology, New York, Macmillan, 1911.
[37] Mass. Exp. Sta. Bull. 161 (1915), p. 125.

salts. Probably the work of Abbott, Conner and Smalley[38] is of more
direct interest here. These investigators found aluminum nitrate to
be toxic to corn seedlings in the presence of nutrient solutions.
E. Kratzmann[39] has reported stimulation due to the presence of small
amounts of aluminum salts. Miyake[40] concludes further that the
effects observed with aluminum chloride cannot be attributed to the
hydrogen ion resulting from the dissociation of the salt.

Aluminum chloride was found to be toxic in every concentration
· used in the present work. The effect of the presence of calcium
chloride in a concentration of .20 M. was to decrease growth still fur-
ther, indicating that its toxic effect, as reflected in growth, was but
additive to that of aluminum chloride. With magnesium chloride
present in equivalent concentration as the calcium chloride, there is a
marked antagonism at a concentration of .000066 M. of aluminum
chloride with .20 M. magnesium chloride. The increase in dry weight
was 100 per cent greater than in an equivalent concentration of
aluminum chloride alone and 300 per cent greater than with mag-
nesium chloride in the concentration given. This culture has been
referred to especially since it furnishes a striking example of antag-
onism between bivalent and trivalent salts, both of which are highly
toxic when used alone. The chloride ion was a constant as far as this
and the preceding series are concerned, the only difference between
the two cases being the use of calcium chloride in one and magnesium
chloride in the other. It seems logical to conclude that the action is
specific as regards the magnesium and aluminum ions. Whatever
the nature of this action may be, it is certainly not shown between
calcium and aluminum ions.

The same general relationships are brought out between ferric
chloride and calcium and aluminum chlorides. Ferric chloride did
not prove toxic in the concentrations used, growth differing but little
from that of the control. When calcium chloride was present in a
concentration of .20 M. throughout the series, growth was half or less
than half that recorded when ferric chloride alone was present.
Magnesium chloride in equivalent concentrations, as the calcium
chloride above, affected growth but little. In other words, magnesium
chloride did not prove toxic in the presence of certain concentrations
of ferric chloride. The relations between the four salts may be briefly
summarized as follows: There is no antagonism shown between alumi-

38 Ind. Exp Sta. Bull. 170 (1913), p. 329.
39 Chem. Ztg., vol. 38 (1914), p. 1040.
40 Jour. Biol. Chem., vol. 25 (1916), p. 23.

num chloride and calcium chloride. There is very little, if any, between ferric chloride and calcium chloride. Magnesium chloride and ferric chloride show marked antagonism in all concentrations used as do magnesium chloride and aluminum chloride in certain concentrations of the two salts. Magnesium chloride and ferric chloride show marked antagonism in all concentrations as do magnesium chloride and aluminum chloride in one concentration of the latter salt.

Reference has already been made to Miss Brenchley's monograph[41] and to the paper by Lipman and Gericke,[42] in which the literature relating to the effects of copper, zinc, and iron salts on plants is reviewed. Suffice it to say that the results reported by different investigators are very conflicting, due largely to the widely different methods used and the varying conditions under which the various data were obtained.

In the present work, copper chloride was toxic in every concentration used. There was marked antagonism between copper and ferric chlorides both from the standpoint of growth and of absorption.

Copper sulphate did not prove to be uniformly toxic. Growth was nearly normal in one concentration used while very much diminished in a lower concentration. The term stimulation might be applied here, but in the present discussion it is applied only when growth due to the presence of an added salt or salts is undoubtedly greater than that in the control.

Toxic effects are correlated with increased absorption and antagonistic effects with decreased absorption as in other series reported.

Growth was always less with zinc sulphate present in the nutrient solution than in the latter alone. Copper and zinc sulphate together were no more toxic than a solution of zinc sulphate alone.

The case with ferric sulphate is clearly one of stimulation. The dry weight was over twice that of the controls in one concentration of the salt used and far superior in several concentrations to that of the plants grown in the controls. Wolff[43] has reported similar results when iron was used in the form of the citrate, an increase in growth comparable to that noted above having been obtained. He found further that nickel or chromium could not be used to replace iron.

The toxic effects of copper sulphate were markedly reduced by the presence of ferric sulphate when we consider the results as a

[41] Inorganic plant poisons and stimulants. 1915.

[42] Univ. Cal. Pub. Agr. Sci., vol. 1 (1917), p. 395.

[43] C.-R. Acad. Sci. (Paris), vol. 157 (1913), p. 1022.

whole, although in one instance growth was greater with copper sulphate alone than when both salts were added together.

The second case of stimulation was noted with zinc sulphate and ferric sulphate in certain concentrations. In series 26 four cultures gave growth superior to that obtained in the control for the series, and throughout growth was good when the two salts referred to above were present together, over the range of concentrations employed. Low absorption was noted. In summarizing the relations of ferric, cupric and zinc sulphates, it is evident, from the discussion above, that zinc sulphate was toxic in every concentration used. Copper sulphate was toxic, but marked variation in degree was shown between various concentrations. Ferric sulphate was stimulating. Copper sulphate and zinc sulphate were no more toxic together than when each was used alone. Ferric sulphate modified somewhat the toxic effects of copper sulphate. Zinc sulphate and ferric sulphate together proved stimulating to the growth of plants. As contrasted with the chlorides, the sulphates of copper and iron were less toxic to barley over the range of concentrations used in this investigation.

Taking the results as a whole, twelve instances of a marked increase in growth at certain definite concentrations of one or more added salts have been noted. With every such increase there is a very notable decrease in the amount of calcium and magnesium absorbed. The increase in growth is attributed to antagonistic salt action; decreased absorption is undoubtedly due to the same action, which tends to preserve the normal permeability of the plasma membrane.

In addition to the twelve instances referred to above, we find in series after series, the toxic effects of the solution in which the plants were growing, noticeable not alone by decreased growth but also by increased absorption. The roots and tops may not show the same relations as regards the amounts of calcium and magnesium taken up. For example, in series 25, in which ferric sulphate and mercuric chloride were used together, the toxicity of the solutions was evident by the very limited growth, yet the composition of the tops was about normal. In the roots, however, the percentage of magnesium was found to be tremendously increased.

It is of interest to refer again to the very low ash content and relatively low absorption, considering the very limited growth, in the few cultures in which mercuric chloride was used alone. It is possible that relatively large amounts of mercuric salts were taken up by the plants which were volatilized on ashing the residue; thus the low percentage of ash may be less surprising.

Possible Effects of Variations in the Concentrations of the Solutions on the Plants

No attempt was made to maintain the total concentration of the nutrient solution constant. This would be exceedingly difficult to do in work of this character, since it would be necessary to vary the concentration of the nutrient solution to maintain the balance of the solution as regards total concentration. The conclusion seems justified that within the range employed the concentration of the nutrient solution is of minor importance as far as growth is concerned. For instance, in table 1, the variation in the concentration of the solution was .279 M. in terms of calcium chloride, yet the total growth varied but little from .001 M. to .28 M. Again in table 2 the growth is very nearly the same at a concentration of .25 M., with calcium and magnesium chlorides, and a total concentration of .54 M. of the same salts. In table 3 the greatest growth occurred in a concentration of .46 M. in terms of the salts above mentioned, while at the lower concentrations of .304 M., growth was but a third that obtained in the higher concentrations. These examples make clear the point above mentioned, namely, that the concentration over the range used was of but minor importance. It is obvious that the above discussion does not apply to the series in which salts of the heavy metals were used, since the variations in concentration in those series were but slight.

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Consideration of a Possible Calcium-Magnesium Ratio

Since Loew[44] first advanced the hypothesis of the lime-magnesia ratio, much experimental evidence has been collected by various investigators both for and against the existence of an optimum ratio between these two elements as regards the growth of plants. The literature bearing upon the subject has been very fully reviewed by Lipman,[45] so that detailed references are not necessary here.

Since the ratios of calcium to magnesium in the solution used by the writer were known and also because of the fact that the analytical data allowed of the calculation of such a ratio for the plants, it seemed of interest to present some of these data here.

The following two tables give the results obtained from two series in which widely varying proportions of calcium and magnesium were used.

[44] Flora, vol. 75 (1892), p. 368.
[45] Plant world, vol. 19 (1916), p. 83.

TABLE 27

Ratio Mg to Ca in solution	Dry weight tops	Ratio Mg to Ca in tops	Dry weight, roots	Ratio Mg to Ca in roots
41 : 1	.3536	2.3 : 1	.1218	1.2 : 1
16 : 1	.5484	4.6 : 1	.1519	1 : 2
8 : 1	.5885	6.0 : 1	.1266	1 : 1
4.1 : 1	.4774	2.6 : 1	.1509	3.3 : 1
2.7 : 1	.3433	2.6 : 1	.1497	1.2 : 1
2.0 : 1	.6775	2.7 : 1	.2119	1.3 : 1
1.6 : 1	.4136	1.2 : 1	.1500	1.3 : 1
1.3 : 1	.4431	1 : 1.2	.1421	1.2 : 1
1 : 1	.3745	1.3 : 1	.1138	1 : 1.3
1 : 1.2	.3268	1.5 : 1	.1254	1 : 1.5
1 : 1.4	.2815	1.8 : 1	.1053	1 : 1.2
1 : 1.8	.5030	1 : 1.2	.1044	1.2 : 1

Table 27 was computed from the results given in table 2. Magnesium chloride was present in uniform concentration of .24 M. with varying concentrations of calcium chloride.

It will be noted that the dry weights with a ratio of magnesium to calcium of 16:1, 8:1, and 1:18 are nearly the same. The ratios of these two elements found in the plants grown in these solutions were 2:1, 1:1, 1:1 2 for the roots, and 1:4.6, 1:1.6, 1:1.2 for the tops. Further, the dry weight of plants grown in a solution in which the ratio was 41:1 and with a ratio of 1:1 are nearly the same. It is evident that the same ratio for the roots may not hold for the tops.

TABLE 28

Ratio Mg to Ca in solution	Dry weight, tops	Ratio Mg to Ca in tops	Dry weight, roots	Ratio Mg to Ca in roots
20.2 : 1	.3033	5.5 : 1	.0822	4.4 : 1
10.5 : 1	.4716	5.4 : 1	.1572	4.7 : '
6.8 : 1	.2799	4.8 : 1	.0780	6.3 : 1
5.1 : 1	.1999	5.8 : 1	.0342	6.0 : 1
4.0 : 1	.1999	4.8 : 1	.0636	7.4 : 1
3.4 : 1	.4363	1.3 : 1	.1122	4.1 : 1
2.5 : 1	.4013	1.8 : 1	.1143	2.8 : 1
2.0 : 1	.2734	2.3 : 1	.0677	4.7 : 1
1.7 : 1	.2603	2.5 : 1	.0867	6.8 : 1

Table 28 gives the ratios in the solutions used in series 4, in which the ratios of magnesium to calcium varied from 20.2:1 to 1.7:1. Growth is nearly the same in solutions in which the ratio was 10.5:1 as in those in which the ratio is 3.4:1 or 2.5:1. The plants grown in these cultures gave the following values for the tops: 5.4:1, 3.4:1, 2.5:1, and for the roots, 4.7:1, 4.1:1, and 2.8:1. There is a tendency for the ratio of calcium to magnesium in the plants to become narrower

as the ratio of these two ions in the solution becomes narrower. Where a wide ratio exists in the solution, there is always a much narrower ratio in the plants.

From the brief discussion above it is evident that the barley plants grew equally well in solutions having widely different ratios of calcium and magnesium ions. There is no "optimum lime-magnesia ratio," as Gile[46] and Wyatt[47] as well as others have shown, and their results are confirmed in the present investigation.

The balance between all the ions present in the solution appears to be of far greater importance than any single ratio. A consideration of the ratios existing between the various ions of the nutrient solution, aside from calcium and magnesium used, is reserved for further study.

Permeability and Antagonism

It is not proposed to enter into a discussion of the structure and composition of the plasma membrane. Davidson[48] has recently summarized our present knowledge concerning it with special reference to selective permeability. A discussion of the various theories which have been advanced to explain antagonistic salt action need not be taken up in detail here. The reader is referred to papers by Clark,[49] Loeb,[50] Osterhout,[51] Loew,[52] Koenig and Paul,[53] True and Gies[54], True and Bartlett,[55] Kearney and Cameron,[65] and Ostwald[57], for a discussion of the various factors which may be of importance in this connection.

The recent work of Clowes[54] and Fenn[59] is important and some very striking similarities between the action of toxic and antagonistic solutions on oil emulsions and on gelatine on the one hand, and plant cells on the other, have been reported by these investigators.

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[46] Porto Rico Exp. Sta., Bull. 12 (1912).
[47] Jour. Agr. Research, vol. 6 (1916), p. 589.
[48] Plant World, vol. 19 (1916), p. 331.
[49] Bot. Gaz., vol. 33 (1902), p. 26.
[50] Archiv. ges. Physiol., vol. 88 (1902), p. 68.
[51] Science, n.s., vol. 35 (1912), p. 112.
[52] Flora, vol. 75 (1892), p. 368.
[53] Zeitschr. Hygiene u. Infektionskrankheiten, vol. 25 (1897), p. 1.
[54] Bull. Torr. Bot. Club, vol. 30 (1903), p. 390.
[55] U. S. Dept. Agr., Bull. 231, 1912.
[56] U. S. Dept. Agr., Bull. 71, 1902.
[57] Archiv. ges. Physiol., vol. 120 (1907), p. 19.
[58] Jour. Phys. Chem., vol. 20 (1916), p. 407.
[59] Proc. Nat. Acad. Sci., vol. 2 (1916), p. 539.

To define normal permeability is very difficult. There seems to be a comparatively wide range of concentration of salts over which the amount of any element taken up may vary without affecting the growth of the plant to any considerable extent. There is likewise a wide range over which the ratio of any one element to any other may change without being detrimental to plant growth. The latter point has been discussed above in connection with a possible 'optimum calcium-magnesium ratio for plants. The first point referred to has been very well treated by Gile and Ageton,[60] so that further reference need not be given here.

For the work in hand the percentage composition of the plants grown in the control cultures seemed to be the most logical criterion of normal permeability available. There are variations between the controls as regards composition, but they are relatively small. On the other hand, the percentages of magnesium, for instance, range from .02 per cent to 9.21 per cent, depending upon the solution used. The percentages of calcium differ over a wide range as well. From the data presented there can be no doubt whatever that the composition of the plant, as regards inorganic constituents at least, may be altered enormously by variations in the surrounding solution.

That portion of the root system in any plant which functions as a semipermeable membrane is obviously of greatest importance in a study of the present kind. The actual area of the membrane which is in contact with the solution must be known in every case before it can be said that the permeability of one root system is greater than that of another. The actual area of the plasma membrane cannot be measured directly because, in the first place, we have no means of determining just how much of the root is involved, and secondly, the area concerned may be changing continually.

Length of the roots and their number and length together as well as green weight and dry weight have been taken as criteria of the existence of antagonism. In the present paper the dry weight has been taken as proportional to the area of the plasma membrane through which salts may enter the plant. It cannot be stated definitely that the two are proportional. They have only been so considered since the dry weight of the plant was the most logical criterion to employ. The reservation must always be made that the two may not be directly proportional, even though they are treated as being so.

That the permeability of the plasma membrane of the plant cells

60 Porto Rico Agr. Exp. Sta. Bull. 16, 1914.

is changed by the nature and balance of the solution surrounding the roots there can be no doubt from the data already given. That a number of ions are capable of acting in a very similar manner to one another as regards permeability is also evident from the present work. Further, the same salt may act differently at different concentrations, preserving nearly normal permeability at some and allowing the penetration of large numbers of ions at others. As previously stated, the total balance of the solution is of vital importance in the preservation of normal permeability, which is in turn correlated with normal growth.

In connection with the salts of the heavy metals, the amounts of the kation of cupric and ferric salts which had penetrated the plant tissue were determined in a number of instances. The percentages found were low. Further, whenever these salts proved toxic, the amounts of calcium and magnesium found in the plants were high; high enough in fact to account for the toxic effect alone. In many instances the percentages of those two elements found were as high in toxic solutions of copper, iron, or zinc salts as when toxic concentrations of calcium or magnesium chlorides were used. We might, therefore, in the light of our present knowledge, be justified in attributing the decreased growth of the plants to the abnormally high absorption of calcium and magnesium and the consequent reactions taking place within the plant cells. The permeability of the membrane must be altered to allow of the presence of these ions in large numbers. The toxic effects due to the presence of large amounts of calcium or magnesium salts might be evident if we could inject solutions of these salts into the plant without altering the permeability of the plasma membrane. But from the present data it seems that the alteration in the permeability of the membrane is the essential consideration.

It is probable also that the toxicity of any solution is accompanied by the increased permeability of the plant tissue to all inorganic salts which are normally found in plants. There may be exceptions as noted already for iron and calcium, but in general this relation holds from the data now at hand.

Ruprecht[61] has localized the effects of aluminum salts in the few layers of cells surrounding the root hairs and attributes the death of the plants grown in solutions of aluminum salts to starvation incident upon the inability of the plant to obtain nutrient salts for normal

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[61] Mass. Exp. Sta. Bull. 161 (1915), p. 125.

metabolism. Forbes[62] has likewise localized the effects of copper salts, when present in toxic concentrations, and concludes that the toxic effect of copper is due to the combination of metal with protein at the growing tips of the roots.

From the experimental results given in the present paper, it is evident that the presence of the salts of each element in toxic concentration results in an increased permeability of the plant tissues to calcium and magnesium at least. Ruprecht's view that plants starve for lack of nutrient salts when grown in toxic solutions is untenable, in the light of the above discussion.

The results of both investigators are significant in indicating the localization of the effect of the two metals studied in the extreme outer portion of the roots, in which the plasma membrane is located.

The results obtained by Loeb with Fundulus eggs, by Osterhout with Laminaria, using electrical conductivity methods, and by Brooks employing microscopical methods with various plant tissues, all point to the preservation of normal permeability as the result of antagonistic salt action. The results reported by these investigators using widely different methods have been confirmed in the present work by the use of a more direct and more nearly quantitative method than any hitherto employed.

It must be recognized, however, that a picture of but one stage in the growth of the plant has been given and that only a portion of the inorganic constituents have been determined. The results reported are essentially those of a static system and must be so considered in comparing them with results obtained by the use of other methods referred to above.

Summary

In the present paper results are given showing the effect of various salt solutions upon the chemical composition of plants, with special reference to a correlation between toxic and antagonistic effects and composition. A uniform nutrient solution was used throughout. The cultures were arranged in series in which the concentration of one salt was kept constant while the concentration of a second salt varied over a wide range. In several series the concentration of both varied, but the ratio between the two remained constant. The analytical data cover the percentages of calcium and magnesium found in the plants grown in every culture, together with determinations

of potassium, iron and copper in certain series. With these facts in mind the results of the investigation may be briefly stated as follows:

The composition of the plants grown in different solutions varied widely.

Normal growth, i.e., approximately that of the controls, was always accompanied by approximately equal percentages of calcium and magnesium in the plants.

In nearly all cases in which the growth of the plants was decreased to a marked extent, the amounts of the two elements referred to above were increased greatly.

The degree of absorption of any salt seems to be independent of the concentration present in the solution over a wide range.

Certain relationships are pointed out between calcium and magnesium absorption and the presence of iron and zinc salts in the solution.

Antagonism as evidenced by growth is correlated with absorption of the ions, which were determined, in every instance.

Stimulation of growth was recorded when ferric sulphate was present in the nutrient solution in certain concentrations and with ferric sulphate and zinc sulphate together.

The amounts of the two ions uniformly determined were not necessarily found in the same proportions in roots and tops.

The possible effects of changes in concentrations of the various solutions are considered, and the conclusion reached that the changes in concentration were of secondary importance over the range of concentrations of the various salts used.

Data are presented showing that growth is the same with widely varying ratios of calcium to magnesium in the nutrient solution.

The results in general confirm those of Loeb, Osterhout, and Brooks in finding that antagonistic salt action tends toward the preservation of normal permeability of the plasma membrane in living tissue.

This problem was suggested by Dr. C. B. Lipman. The writer wishes to express his thanks for this and for many other valuable suggestions offered while the work was in progress. The writer is also indebted to Prof. L. T. Sharp for helpful advice.

NOTE

The following key applies to all the graphs. The numbers on the abscissas represent both the actual weight of tops and roots and percentages of calcium and magnesium, or of iron, when the latter were plotted. The numbers on the ordinates correspond to the number of cultures as given in the table on the opposite page. The heavy lines always refer to the roots, the light lines to the tops.

The following type lines are used:

——————————————————————— (Solid line) Weight of tops.

—— —— —— —— (Short dashes) Weight of roots.

— —— —— (Long dashes) Percentage of calcium.

—— —— —— (One long and two short dashes) Percentage of magnesium.

—— —— (One long and one short dash) Percentage of iron.

The numbers given in the "Explanation of Plates" always refer to the plants arranged in order from left to right, the control being on the extreme right in every case.

TABLE 1

Calcium Chloride

No.	Solution CaCl$_2$	Dry weight	Mean	Percentage of Ash	Mean	Percentage of Ca	Mean	Percentage of Mg	Mean
1	.002	Tops .7633		15.38		.477		.051	
		.7104	.7368	15.34	15.36	......	.477	.046	.049
		Roots .3608	.1804	26.24		.231		.413	
2	.004	Tops .6486		15.34		.400		.116	
		.4976	.5731	17.34	16.34	.470	.435	.154	.135
		Roots .6555	.3277	29.98		.261		.507	
3	.01	Tops .6419		17.29		.514		.095	
		.6138	.6279	16.81	17.05	.517	.515	.078	.086
		Roots .5628	.2814	28.10		.219		.498	
4	.02	Tops .4814		16.80		.504		.045	
		.6600	.5707	17.69	17.24	.450	.477	.044	.045
		Roots .5750	.2875	31.56		.121		.483	
5	.04	Tops .5950		17.52		.640		.048	
		.5442	.5696	16.59	17.05	.565	.602	.044	.046
		Roots .5959	.2979	33.54		.113		.563	
6	.06	Tops .5692		17.67		.718		.050	
		.4998	.5845	17.00	17.33	.713	.715	.087	.069
		Roots .5048	.2524	29.45		.098		.420	
7	.08	Tops .6706		13.92		.407		.035	
		.5015	.5860	11.82	12.87	.684	.545	.079	.057
		Roots .5250	.2625	29.46		.363		.472	
8	.10	Tops .6114		18.46		.428		.061	
		.4182	.5148	19.94	19.20	.440	.434	.068	.064
		Roots .3827	.1913	30.18		.290		.652	
9	.12	Tops .4832		16.80		.443		1.000	
		.4778	.4805	17.15	16.97	.425	.434	.82	.962
		Roots .3918	.1959	29.12		.273		.810	
10	.16	Tops .5668		17.45		.387		1.340	
		.5218	.5443	18.47	17.96	.486	.436	1.300	1.32
		Roots .6123	.3066	29.43		.392		.415	
11	.20	Tops .5687		17.03		.348		.358	
		.7637	.6662	17.13	17.08	.388	.368	.282	.320
		Roots .6305	.3154	31.82		.204		.407	
12	.24	Tops .5266		17.62		.354		.316	
		.5793	.5529	17.34	17.48	.392	.373	.137	.226
		Roots .6067	.3033	27.08		.373		.577	
Full Nutrient		Tops .7937		18.80		.393		.235	
		.7418	.7677	19.10	18.95	.390	.391	.202	.218
		Roots .6900	.3450	20.03		.227		.259	

Grown October 24–December 5, 1915.
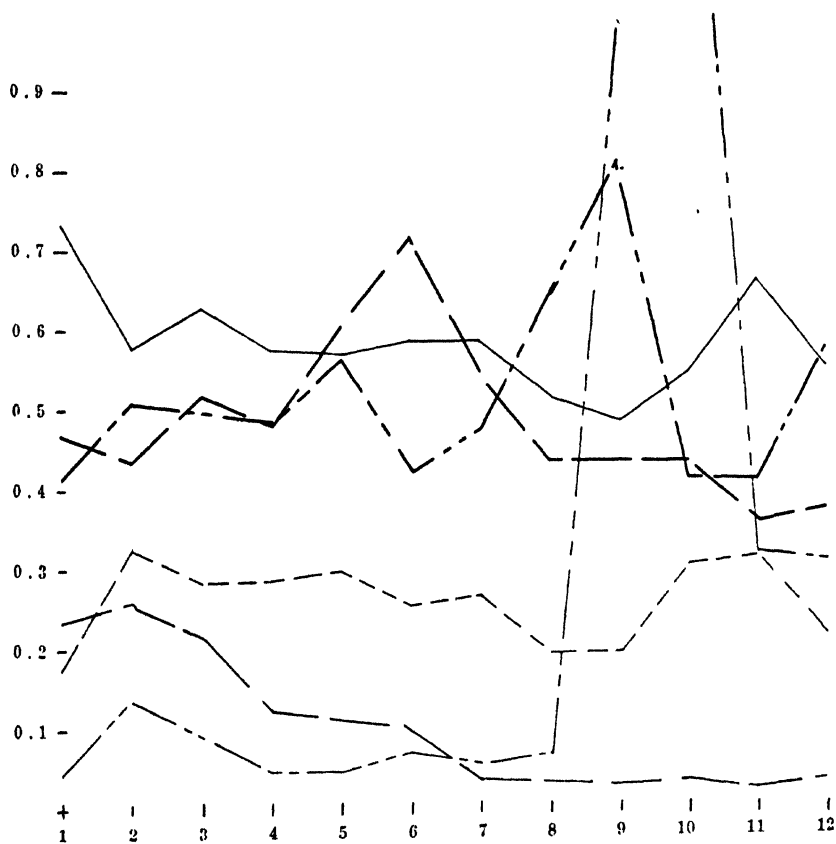
Fig. 1
Calcium Chloride
(See Table 1)

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TABLE 2

Magnesium Chloride + Calcium Chloride

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No.	Solution MgCl₂	CaCl₂	Dry Weight	Mean	Percentage of Ash	Mean	Percentage of Ca	Mean	Percentage of Mg	Mean	Percentage of Fe	Mean
1	.24	.004	Tops .3407		12.90		.483		1.21		......	
			.3666	.3536	13.00	12.95	.500	.491	1.06	1.16	......	
			Roots .2456	.1218	20.05		.557		.670		.022	
2	.24	.01	Tops .5106		16.84		.198		.883		......	
			.5862	.5484	16.88	16.86	.196	.197	.953	.918	......	
			Roots .3038	.1519	16.75		.437		.216		.025	
3	.24	.02	Tops .2758		15.22		.490		1.45		......	
			.5885	.4321	15.94	15.58	.189	.339	1.09	1.13	......	
			Roots .2533	.1266	21.02		.407		.433		.010	
4	.24	.04	Tops .4450		16.30		.361		.967		.943	
			.4828	.4619	.17.55	16.92	.342	.351	.920	.943	......	
			Roots .3018	.1509	16.32		.550		1.82		.009	
5	.24	.06	Tops .3150		18.50		.445		1.07		... .	
			.3716	.3433	17.87	18.18	.403	.422	1.13	1.10	..... .	
			Roots .2994	.1497	19.54		.309		.388		.006	
6	.24	.08	Tops .6871		15.97		.154		.440		. ....	
			.6679	.6775	....	15.97	.172	.163	.441	.440	......	
			Roots .4238	.2119	14.25		.206		.280		.007	
7	.24	.10	Tops .4797		16.75		.458		.645		....	
			.4476	.4636	13.23	14.99	.457	.457	.507	.576	.....	
			Roots .3000	.1500	19.95		.430		.577		.002	
8	.24	.12	Tops .4583		16.20		.817		.665		......	
			.4279	.4431	17.43	16.81	.732	.774	.635	.650	... ..	
			Roots .2843	.1421	23.09		.376		.454		.006	
9	.24	.16	Tops .3243		15.14		1.160		1.46		......	
			.3543	.3393	15.45	15.29	1.210	1.18	1.59	1.52	. ...	
			Roots .2276	.1138	24.60		.970		.714		.010	
10	.24	.20	Tops .3404		16.62		1.140		1.69		. ...	
			.3132	.3268	17.50	17.06	1.330	1.23	1.98	1.83	......	
			Roots .2508	.1254	24.60		1.200		.785		.012	
11	.24	.24	Tops .2707		18.53		1.640		.807		.015	
			.2924	.2815	17.83	18.18	1.290	1.46	.826	.816	.009	.012
			Roots .2107	.1053	24.62		1.200		.995		.010	
12	.24	.30	Tops .4834		18.48		.563		.675		.010	
			.5226	.5030	17.64	18.06	.585	.574	.707	.691	.012	.012
			Roots .3888	.1944	25.16		.437		.538		.010	
13	.24		Tops .4281		16.83		.387		.907		.018	
			.5106	.4693	17.20	17.02	.383	.385	.890	.898	.013	.015
			Roots .2463	.1231	23.07		.208		.800		.011	

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Grown January 2–February 13, 1916.

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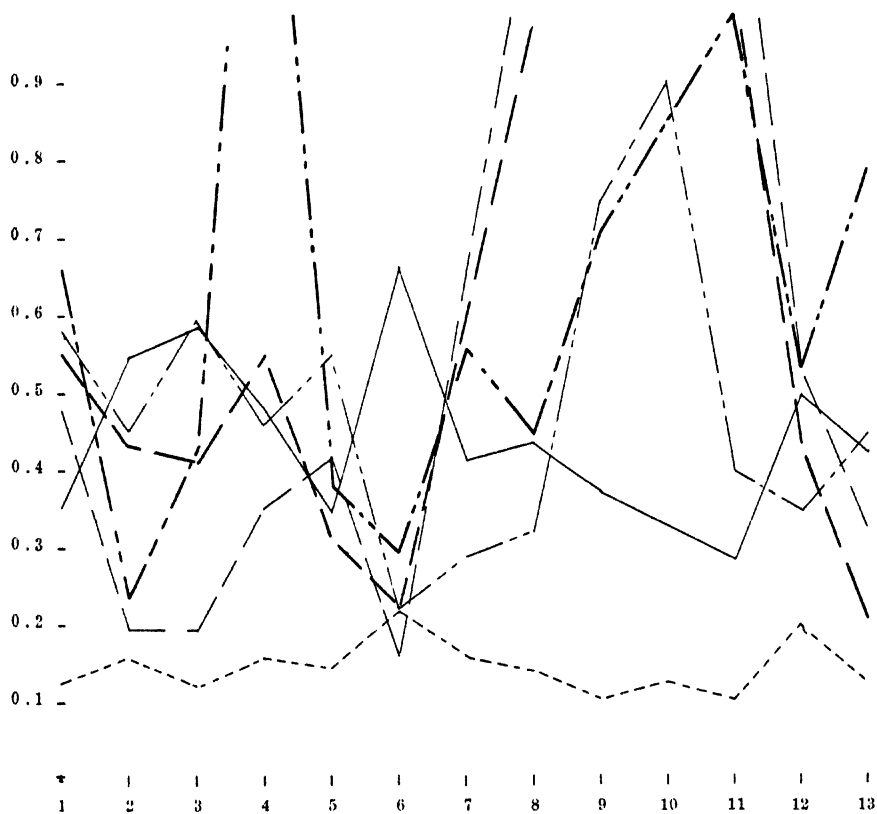
Fig. 2
Magnesium Chloride + Calcium Chloride
(See Table 2)

TABLE 3

Magnesium Sulphate + Calcium Chloride

No.	Solution		Dry Weight	Mean	Percentage of Ash	Mean	Percentage of Ca	Mean	Percentage of Mg	Mean
	$MgCl_2$	$CaCl_2$								
1	.30	.001	Tops .1986		16.60		.300		.440	
			Roots .2650	.2318	15.60	16.10	.209	.259	.413	.426
2	.30	.002	Tops .2700		16.44		.198		.571	
			Roots .2766	.2733	16.39	16.41	.143	.170	.514	.542
3	.30	.004	Tops .2566		18.43		.216		.595	
			Roots .2236	.2401	17.39	17.91	.274	.255	.533	.564
4	.30	.01	Tops .3194		16.49		.229		.515	
			Roots .1744	.2469	14.28	15.38	.189	.209	.088	.515
5	.30	.02	Tops .2074		14.56		.526		.749	
			Roots .2249	.2163	15.73	15.14		.526	.565	.607
6	.30	.04	Tops .5249		15.19		.423		.405	
			.4166	.4707	15.57	15.38	.396	.409	.437	.418
			Roots .1309	.0654	18.10		.443			
7	.30	.06	Tops .3036		16.83		.254		.649	
			.1836	.2436	17.42	17.12	.145	.254	.790	.719
			Roots .0850	.0425	14.70		.263			
8	.30	.08	Tops .2184		17.90		.235		.700	
			.2403	.2293	15.99	16.94	.213	.224	.663	.681
			Roots .0648	.0324	13.05		.104		.230	
9	.30	.10	Tops .3978		30.08		.525		1.15	
			Roots			30.08		.525		1.15
10	.30	.12	Tops .3842		17.92		.329		.399	
			.2759	.3300	19.57	18.74	.388	.358	.563	.481
			Roots .1059	.0529	27.29		.623		.124	
11	.30	'.16	Tops .8819		17.41		.136		.047	
			.9600	.9209	18.11	17.76	.184	.160	.037	.042
			Roots .6900	.3450	33.71		.435		.047	
12	.30	.20	Tops .2100							
			Roots .2700	24.00		14.08		1.390		3.660
13	.30	.24	Tops .2576							
			Roots .1930	.2253		15.40		1.490		4.210
14	.30	.30	Tops .2600							
			Roots .2000	.2300		14.30		2.200		3.790
Full Nutrient			Tops .7937		18.80		.393		.235	
			.7418	.7677	19.10	18.95	.390	.391	.202	.218
			Roots .6900	.3450	20.03		.527		.259	

Grown October 24 to December 5, 1915.
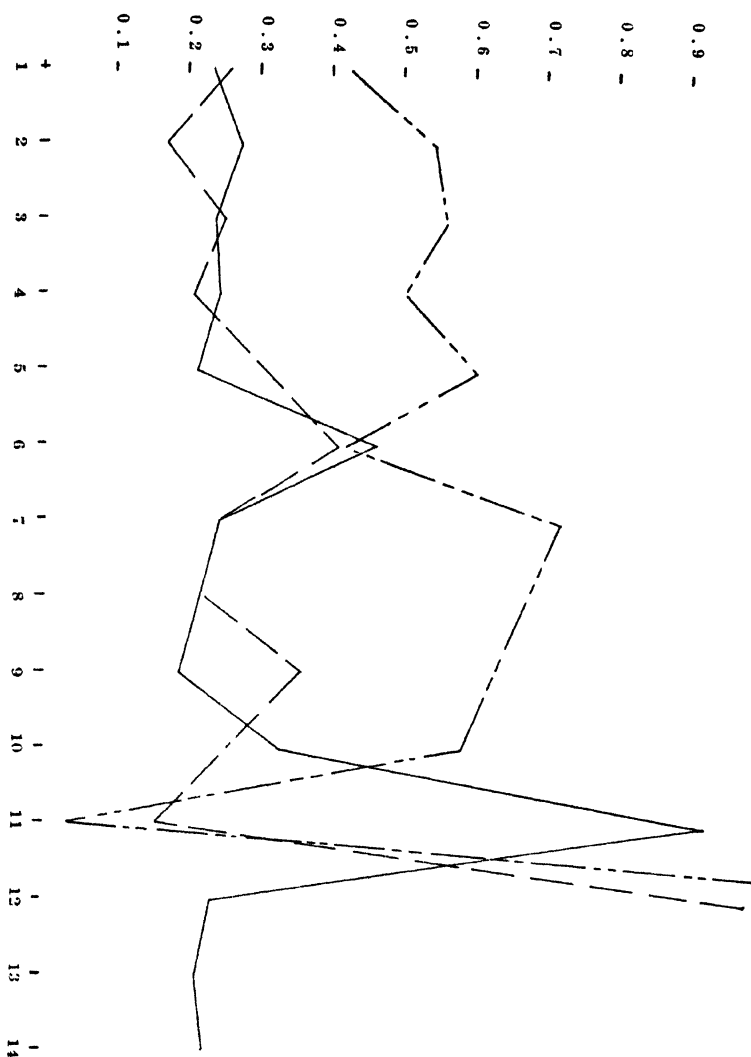
Fig. 3
Magnesium Chloride + Calcium Chloride
(See Table 3)

TABLE 4

Magnesium Chloride + Calcium Chloride

No.	Solution MgCl₂	Solution CaCl₂		Dry Weight	Mean	Percentage of Ash	Mean	Percentage of Ca	Mean	Percentage of Mg	Mean	Percentage of Fe	Mean
1	.36	.02	Tops	.2878		18.24		.271		1.71			
				.3189	.3033	17.12	17.68	.311	.291	1.51	1.61		
			Roots	.1644	.0822	18.15		.221		.98			
2	.36	.04	Tops	.4128		18.25		.374		1.89		.039	
				.5210	.4716	16.55	17.40	.342	.358	1.99	1.94	.047	.043
			Roots	.3144	.1572	20.65		.263		1.24			
3	.36	.06	Tops	.2952		16.31		.431		2.14			
				.2640	.2799	17.21	16.76	.392	.461	2.37	2.25		
			Roots	.1560	.0780	17.90		.472		3.00			
4	.36	.08	Tops	.1878		18.10		.394		2.22			
				.2034	.1999	24.00	21.05	.407	.400	2.48	2.35		
			Roots	.0684	.0342	17.80		.733		4.43			
5	.36	.10	Tops	.2292		15.13		.532		2.90			
				.1698	.1999	16.20	15.66	.614	.573	2.61	2.75		
			Roots	.1272	.0636	17.90		.631		4.71			
6	.36	.12	Tops	.4788		14.60		.817		.890		.042	
				.3938	.4363	13.65	19.12	.625	.721	1.02	.95	.027	.034
			Roots	.2244	.1122	17.60		.813		3.33		......	
7	.36	.16	Tops	.3616		14.12		.832		1.23			
				.4410	.4013	15.17	14.64	.742	.787	1.72	1.47		
			Roots	.2287	.1143	16.00		.873		2.47			
8	.36	.20	Tops	.2963		13.21		.931		2.01			
				.2505	.2734	12.17	12.69	.871	.931	2.32	2.16		
			Roots	.1355	.0677	16.99		1.020		4.82			
9	.36	.24	Tops	.3100		14.21		.870		2.31			
				.2106	.2603	13.17	13.69	1.200	1.03	3.02	2.66		
			Roots	.1734	.0867	14.20		.713		4.89			
Full Nutrient			Tops	.7819		20.40		.349		.223			
				.7459	.7639	19.70	20.05	.330	.339	.268	.295		
			Roots	.6209		21.70		.242		.248			

Grown January 7–February 21, 1916.

Fig. 4
Magnesium Chloride + Calcium Chloride
(See Table 4)

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TABLE 5

Magnesium Sulphate

No.	Solution MgSO4	Dry Weight		Mean	Percent of Ash	Mean	Percent of Ca	Mean	Percent of Mg	Mean
1	.06	Tops	.7326		16.78		.358		.785	
			.7838	.7587	16.46	16.62	.379	.368	.750	.767
		Roots	.6383	.3191	16.84		.495		.550	
2	.10	Tops	.7150		15.73		.302		.320	
			.9420	.8276	16.21	15.97	.313	.307	.320	.320
		Roots	.4822	.2411	22.91		.580		1.270	
3	.14	Tops	.6888		15.09		.201		.350	
			.6546	.6717	15.64	15.36	.230	.215	.390	.370
		Roots	.4437	.2218	20.31		.148		.740	
4	.16	Tops	.3042		12.65		.337		.350	
			.3657	.3349	11.81	12.23	.331	.334	.310	.330
		Roots	.0762	.0381	21.52		.985		1.01	
5	.18	Tops	.2875		12.32		.496		.280	
			.2978	.2926	12.72	12.52	.371	.434	.310	.295
		Roots	.0542	.0271	20.49		1.130		1.300	
Full Nutrient		Tops	.7819		20.40		.349		.223	
			.7459	.7639	19.70	20.05	.330	.339	.268	.295
		Roots	.6209		21.70		.242		.248	

Grown December 9–January 20, 1915-16
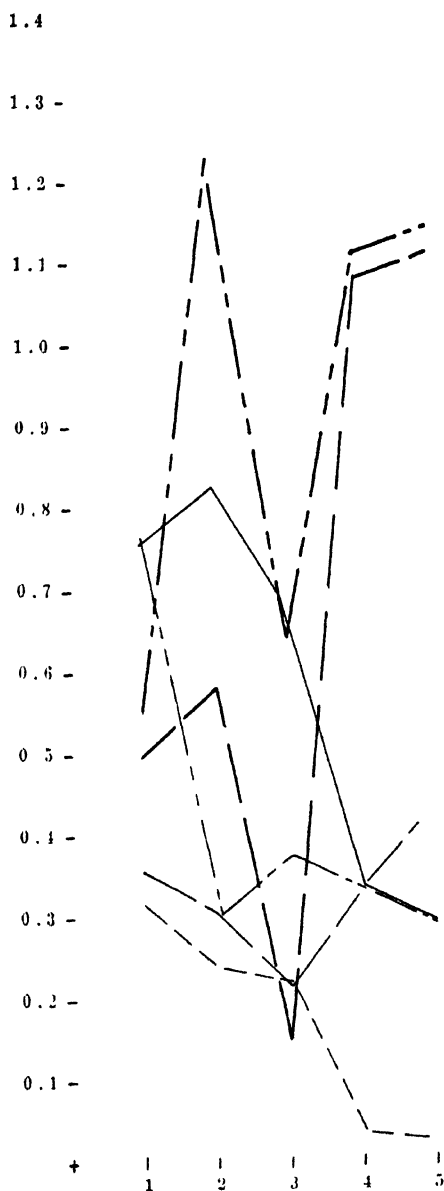
Fig. 5
Magnesium Sulphate
(See Table 5)

TABLE 6

Magnesium Chloride + Calcium Chloride

No.	Solution CaCl₂	MgSO₄	Dry Weight		Mean	Percentage of Ash	Mean	Percentage of Ca	Mean	Percentage of Mg	Mean	Percentage of Fe	Mean
1	.04	.18	Tops	1.1626		19.91		.261		.407		.036	
				1.2526	1.2076	19.75	19.83	.332	.296	.722	.564	.023	.030
			Roots	.9895	.4942	16.52		.030		.312		.017	
2	.08	.18	Tops	1.1888		20.43		.312		.077		.060	
				1.0948	1.1418	21.15	20.79	.377	.344	.084	.081	.060	.060
			Roots	.9037	.4518	26.13		.151		.180		.020	
3	.12	.18	Tops	1.1287		19.50		.275		.021		.024	
				1.2691	1.1989	21.22	20.36	.276	.275	.023	.022	.021	.023
			Roots	.9591	.4795	20.93		.560		.185		.020	
4	.16	.18	Tops	1.2293		17.85		.169		.035		.036	
				1.2134	1.2213	16.75	17.30	.131	.150	.049	.042	. .	.036
			Roots	.5444	.2722	16.47		.690 .		.101		.024	
5	.20	.18	Tops	1.1786		21.67		.333		.039		.033	
				1.1021	1.1403	21.07	21.37	.256	.294	.044	.041	.	.033
			Roots	1.0500	.5250	25.40		.820		.299		.028	
6	.24	.18	Tops	.9773		21.47		.448		.462		.045	
				.9923	.9848	21.65	21.56	.545	' .496	.486	.470	.033	.039
			Roots	.8600	.4300	26.07		1.290		.407		.024	
7	.28	.18	Tops	.8459		18.62		.476		.437		.032	
				.7450	.7954	20.05	19.33	.523	.499	.409	.420	.037	.035
			Roots	.6014	.3007	24.87		1.580		.565		.023	
8	.32	.18	Tops	.4608		21.43		.640		1.05		.027	
				.5316	.4962	....	21.43	.568	.604	1.24	1.14	.019	.023
			Roots	.3350	.1675	29.00		3.330		1.07		.026	
9	.36	.18	Tops	.1916		18.56		.747		1.43		.048	
				.2349	.2132	18.80	18.68	.955	.851	1.59	1.50	.049	.047
			Roots	.0976	.0488	18.05		1.000		2.80			
				.2269	.1819	13.60	13.50	.235	.370	1.71	1.71	.031	.053
10		.18	Tops	.1369		13.40		.505		2.03		.016	
			Roots	.0614	.0307	16.62		.112		3.68			

Grown January 24–March 6, 1916.
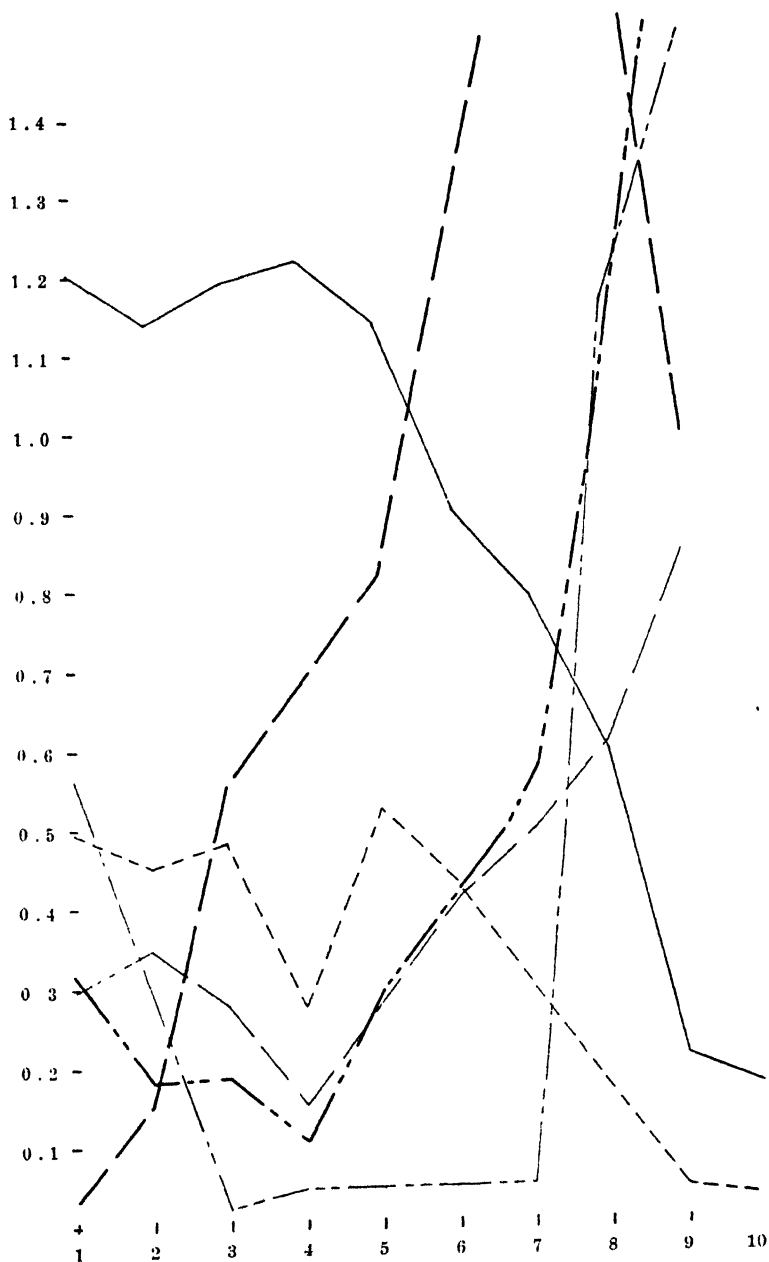
Fig. 6
Magnesium Sulphate + Calcium Chloride
(See Table 6)

TABLE 7

Potassium Chloride

No.	Solution Ca(NO₃)₂	MgSO₄	Dry Weight		Mean	Percentage of Ash	Mean	Percentage of Ca	Mean	Percentage of Mg	Mean	Percentage of Fe	Mean
1	.04	.15	Tops	1.8850		17.90		.067		.967		.026	
				1.1941	1.5395	20.00	18.95	.067	.067	.808	.887	.018	.022
			Roots	.9776	.4588	19.35		.062		.101		.093	
2	.08	.15	Tops	1.7825		16.20		.101		.762		.024	
				1.5648	1.6731	16.92	16.56	.120	.110	.842	.802	.021	.023
			Roots	.8813	.4406	25.37		.135		.430		.012	
3	.12	.15	Tops	1.6850		19.90		.487		2.190			
				....	.8425	....	19.90	... ..	.487		2.190		
			Roots	.6284	.3141	31.20		.037		2.390			
4	.16	.15	Tops	1.2078		16.67		.247		2.120			
				....	.6030	....	16.67	......	.247	......	2.120		
			Roots	.5668	.2834	27.80		.037	,	2.410			
5	.20	.15	Tops	....		No growth							
			Roots	....									
6	.24	.15	Tops	.5818		18.50		.550		9.20			
				....	.2909	....	18.50	......	.550	..... .	9.200		
			Roots	.1581	.0740	21.90		.195		6.520			
7	.28	.15	Tops	....		No growth							
			Roots	....									
8	Full Nutrient		Tops	1.5682		18.33		.293		.231			
				1.5775	1.5728	19.40	18.86	.312	.302	.279	.255		
			Roots	.9776		20.40		.271		.279			

Amounts too small to determine.

Grown April 14–May 27, 1916.
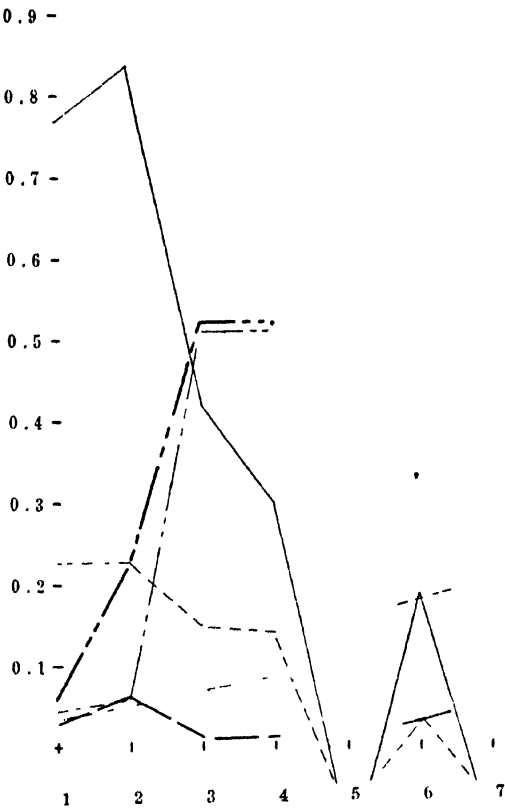
Fig. 7
Magnesium Sulphate + Calcium Nitrate
(See Table 7)

TABLE 8

Magnesium Sulphate + Calcium Nitrate

No.	Solution KCl		Dry Weight	Mean	Percentage of Ash	Mean	Percentage of Ca	Mean	Percentage of Mg	Mean	Percentage of Fe	Mean	Percentage of K	Mean
1	.04	Tops	1.1563		19.65		.078		.228		.028		1.37	
			1.1128	1.1345	19.65	19.65	......		.201	.214	.045	.037	1.80	1.58
		Roots	.5038	.2519	17.07		.256		.175		.173		.61	
2	.06	Tops	1.0773		24.00		.128		.083		.041		3.54	
			1.0791	1.0782	25.90	24.95	.113	.120	.118	.100	.030	.036	3.54	3.54
		Roots	.5979	.2989	16.27		.241		.170		......		. ...	
3	.08	Tops	.7638		27.50		.302		.201		.064		4.81	4.56
		Roots	.4659	.1829	17.20		.238		.180		.106		4.80	
4	.10	Tops	.8417		25.90		.204		.302		.268		3.56	
			.7900	.8158	24.40	25.15	.186	.195	.205	.253	.280	.274	3.80	3.68
		Roots	.3135	.1567	14.20		.570		.300		.072		1.02	
5	.12	Tops	.5656		31.00		.283		.378		.195		4.78	
			.5815	.5734	29.80	30.40	.265	.274	.657	.567	.072	.133	4.30	4.54
		Roots	.2215	.1107	18.00		.780		.101		.175		1.67	
6	.14	Tops	.4825		39.50		.217		.478		.091		9.11	
			.4200	.4531	32.30	35.90	.222	.219	.454	.466	.092	.091	7.10	8.10
		Roots	.1762		20.83		.617		.139		.021		1.53	
7	.16	Tops	.5375		42.00		.248		.730		.071		......	
			....	.2687	....	42.00	...	.248	......	.730	.. ...	.071	11.21	11.21
		Roots	.1339	.0669	23.83		.505		1.34		.250		2.31	

Grown January 31–March 13, 1916.
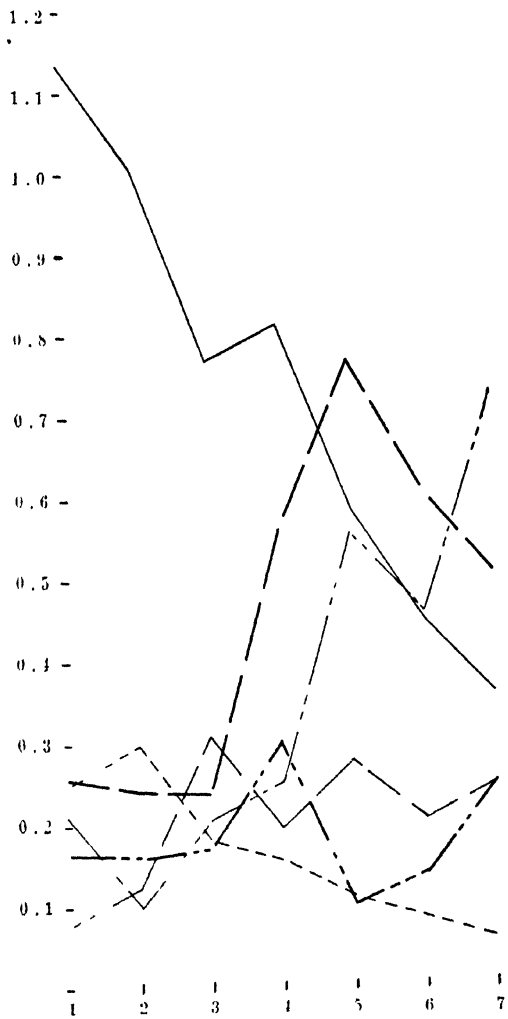
Fig. 8
Potassium Chloride
(See Table 8)

TABLE 9

Magnesium Sulphate + Potassium Chloride

Solution				Dry Weight	Mean	Percentage of Ash	Mean	Percentage of Ca	Mean	Percentage of Mg	Mean	Percentage of Fe	Percentage of K	Mean
No.	MgSO₄	KCl												
1	.04	.18	Tops	.6579		19.65		.141		.490			2.13	
				.6379	.6479	21.20	20.42	.162	.151	.500	.495		1.72	1.92
			Roots	.2800	.1400	20.00		......		2.79			.67	
2	.08	.18	Tops	.6800		22.07		.138		.430			3.21	
				.7162	.6981	25.10	23.58	.171	.154	.480	.455		3.00	3.10
			Roots	.2682	.1341	23.50		.590		1.350			.72	
3	.12	.18	Tops	.4957		22.60		.292		......			3.78	
				.5202	.5079	26.50	24.55	.310	.301	.923	.923		3.82	3.80
			Roots	.2200	.1100	25.25		.745		.104			.86	
4	.16	.18	Tops	.6229		23.50		.152		.382			4.12	
				.6464	.6346	24.70	24.10	.169	.161	.381	.381		4.21	4.16
			Roots	..3123	.1561	22.70		.291		..561			1.40	
5	.20	.18	Tops	.3643		26.20		.440		.977		Amounts too small to determine.	5.01	
				.4819	.4231	....	26.20	......	.440	......	.977		.... .	5.01
			Roots	.2063	.1031	24.00		.678		1.060			2.20	
6	.24	.18	Tops	.3259		33.20		.407		1.040			7.22	
				.2141	.2700	37.60	35.40	.423	.415	2.920	1.970		8.13	7.66
			Roots	.1297	.0648	22.10		.750		1.490			2.80	
7	.28	.18	Tops	.1522		31.10		.299		1.030			9.20	
				.2050	.1786	35.10	33.10	.265	.282	.990	1.010		11.30	10.25
			Roots	.0913	.0456	24.10		.735		2.900			3.10	
8	.32	.18	Tops	.2704		36.10		.263		.890			11.20	
				.2997	.2850	36.20	36.15	.211	.237	.810	.850		7.20	9.20
			Roots	.1467	.0733	22.57		.229		.818			2.17 .	
9	.36	.18	Tops	.2800		23.90		.261		.801			3.21	
				.2846	.2823	25.00	24.45	.278	.269	.895	.848		4.17	3.64
			Roots	.1417	.0708	21.60		.699		.248			2.18	
Full Nutrient			Tops	1.0992		20.17		.310		.268				
				1.0750	1.0872	19.12	18.69	.297	.303	.228	.224			
			Roots	.8120		20.00		.271		.233				

Grown January 31–March 13, 1916.

Fig. 9
Magnesium Sulphate + Potassium Chloride
(See Table 9)

TABLE 10

Aluminum Chloride

No.	Solution AlCl₃	Dry Weight		Mean	Percent of Ash	Mean	Percent of Ca	Mean	Percent of Mg	Mean	Percent of Fe	Mean
1	.0000033	Tops	.4438		22.42		.098		.450		.075	
			.4688	.4563	20.40	21.40	.092	.095	.590	.520	.077	.076
		Roots	.4315	.2157	20.20		.055		.590		.089	
2	.0000165	Tops	.2934		23.20		.196		.793		.151	
			.2745	.2839	22.70	22.95	.180	.188	.793	.793	.140	.145
		Roots	.1976	.0988	18.70		.250		.990		.061	
3	.000033	Tops	.2872		21.09		.316		.953		.173	
			.3595	.3233	22.60	21.84	.321	.318	1.000	.970	.154	.163
		Roots	.2964	.1482	19.55		.153		.504		.130	
4	.000066	Tops	.3028		21.09		.342		.605		.128	
			.3200	.3114	22.80	21.94	.334	.338	.615	.610	.155	.141
		Roots	.2422	.1211	19.55		.334		.840		.171	
5	.000132	Tops	.2720		22.60		.423		.835		.101	
			.2479	.2599	19.00	20.80	.450	.436	.837	.836	.134	.117
		Roots	.2645	.1322	26.60		.382		1.110		.104	
6	.000331	Tops	.3178		20.20		.246		1.130		.137	
			.4016	.3597	21.90	21.05	.247	.246	.690	.91	.124	.130
		Roots	.2550	.1275	27.90		.108		.		.108	
7	.00331	Tops	.3863		22.30		.258 .		.535		.114	
			.2369	.3116	21.82	22.60	.268	.263	1.230	.88	.187	.150
		Roots	.2153	.1076	29.40		.583		.330		.231	

Grown August 26 October 7, 1916.
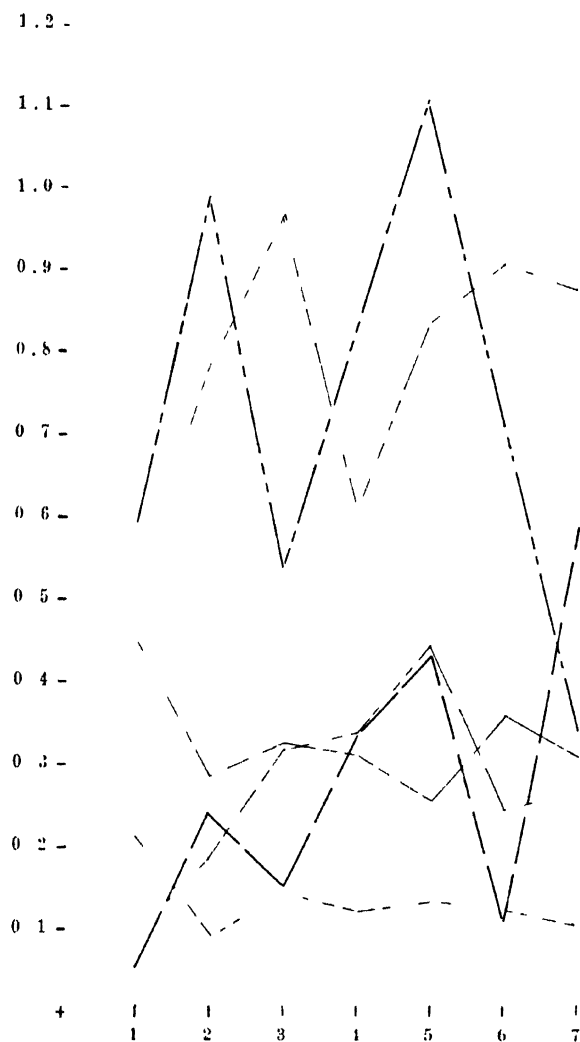
Fig. 10
Aluminum Chloride
(See Table 10)

TABLE 11

Calcium Chloride + Aluminum Chloride

No.	Solution AlCl₃	CaCl₂	Dry Weight		Mean	Percentage of Ash	Mean	Percentage of Ca	Mean	Percentage of Mg	Mean	Percentage of Fe	Mean
1	.0000033	.20	Tops	.2962		24.20		1.630		.745		......	
				.2087	.2524	23.10	23.65	1.820	1.72	.830	.787	......	
			Roots	.1897	.0948	20.40		.730		.872		......	
2	.0000165	.20	Tops	.2542		24.23		1.610		.890		.123	
				.2678	.2610	22.18	23.20	1.720	1.66	9.30	.910	.313	.21
			Roots	.2745	.1372	26.17		.731		......		......	
3	.0000331	.20	Tops	.3324		23.00		1.250		.787		.503	
				.3706	.3515	25.20	24.10	1.460	1.35	.903	.845	.540	.52
			Roots	.2942	.1471	26.10		.790		.817		.075	
4	.0000662	.20	Tops	.2139		23.20		1.210		.821		.237	
				.2337	.2238	21.70	22.45	1.030	1.12	.733	.772	.114	.17
			Roots	.1839	.0919	24.20		.621		1.02		. . .	
5	.000132	.20	Tops	.2148		20.58		1.400		.932		.248	.18
				.3085	.2611	24.10	22.34	1.060	1.23	.897	.913	.119	.18
			Roots	.2239	.1119	20.20		.513		.947		....	
6	.000331	.20	Tops	.2337		24.10		1.420		.632		.105	
				.2137	.2237	21.32	22.71	1.270	1.34	.711	.621	.210	.15
			Roots	.1682	.0841	20.16		.672		1.310		......	
7	00331	.20	Tops	.2496		24.10		1.330		.490		.155	
				.1946	.2221	22.90	23.50	1.550	1.44	.516	.503	.285	.22
			Roots	.1296	.0648	26.40		.780		.253		.021	
Full Nutrient			Tops	.7103		18.17		.322		.221			
				.7327	.7215	19.31	18.74	.377	.349	.270	.245		
			Roots	.6600	.3300	19.99		.300		.233			

Grown August 26–October 7, 1916
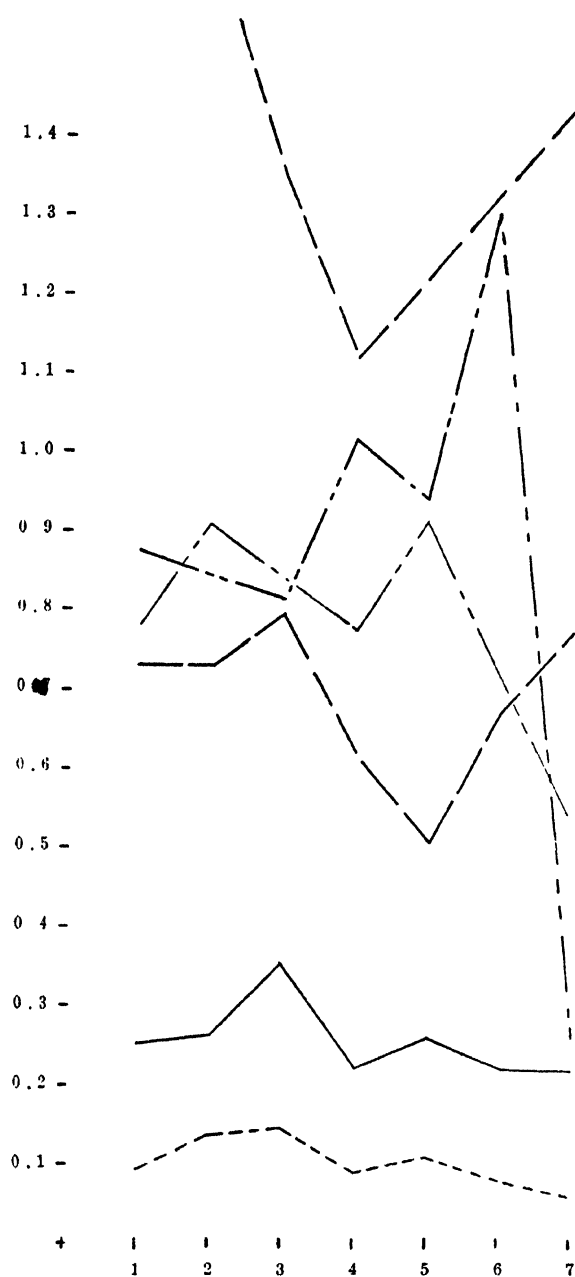
Fig. 11
Calcium Chloride + Aluminum Chloride
(See Table 11)

TABLE 12

Aluminum Chloride + Magnesium Chloride

No.	AlCl₃	MgCl₂	Dry Weight	Mean	Percent Ash	Mean	Percent of Ca	Mean	Percent of Mg	Mean	Percent	Mean
1	.0000033	.20	Tops .2819		19.02		.426		2.13		.121	
			.5457	.4138	18.71	18.86	.371	.398	1.91	2.02	.131	.126
			Roots .2936	.1468	21.31		.321		2.12		.122	
2	.0000165	.20	Tops .3539		17.31		.327		1.71		.141	
			.3000	.3269	19.21	18.16	.421	.374	1.83	1.77	.132	.136
			Roots .1750	.0875	22.17		.400		1.71		.101	
3	.0000331	.20	Tops .2243		21.05		.352		2.51		.148	
			.2259	.2251	17.70	19.39	.448	.400	2.80	2.65	.117	.147
			Roots .1239	.0614	24.10		.366		1.96		.135	
4	.0000662	.20	Tops .6327		19.00		.147		1.46		.050	
			.7644	.6985	18.10	18.55	.130	.138	1.36	1.42	.047	.049
			Roots .5526	.2763	19.95		.111		.333		.040	
5	.000132	.20	Tops .2406		19.75		.280		2.78		.069	
			.3156	.2781	19.55	19.65	.282	.281	3.11	2.94	.064	.066
			Roots .1250	.0625	24.00		.186		5.88		.181	
6	.000331	.20	Tops .2279		16.50		.407		.940		.091	
			.2048	.2163	19.90	18.20	.467	.437	.557	.74	.081	.086
			Roots .1700	.0850	22.76		.302		2.51		.098	
7	.00331	.20	Tops .2400		17.40		.131		2.14		.161	
			.1450	.1925	18.80	18.10	.161	.145	1.71	1.92	.192	.176
			Roots .0990	.0495	32.60		.200		4.53		.439	

Grown August 26–October 7, 1916.
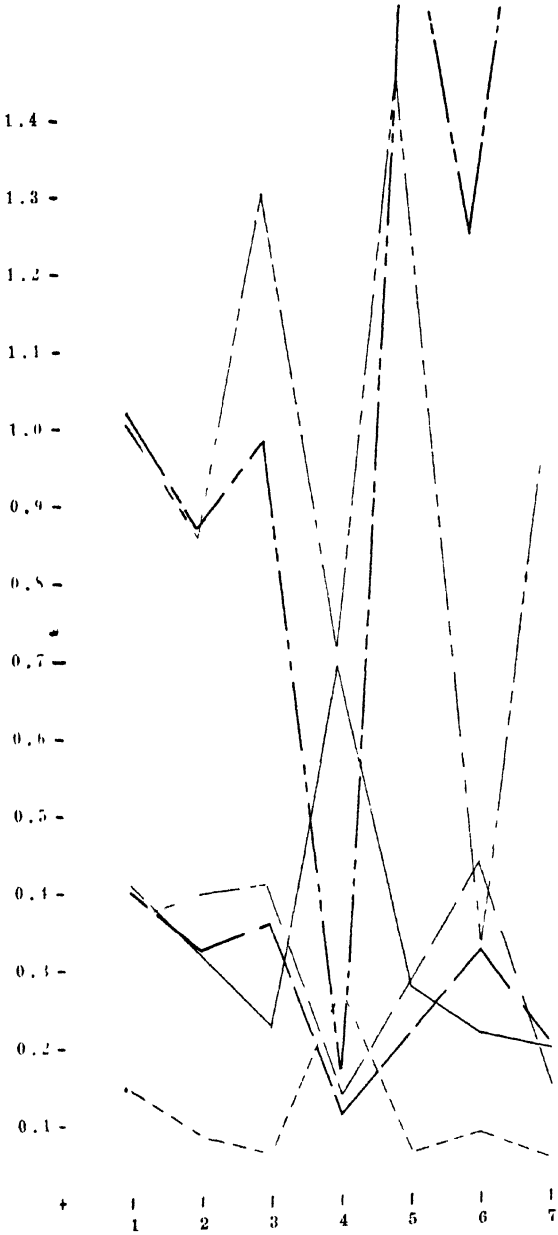
Fig. 12
Aluminum Chloride + Magnesium Chloride
(See Table 12)

TABLE 13

Ferric Chloride

No.	Solution FeCl₃	Dry Weight		Mean	Percentage of Ash	Mean	Percentage of Ca	Mean	Percentage of Mg	Mean	Percentage of Fe	Mean
1	.000089	Tops	.7712		14.50		.199		.258		.214	
			.8376	.8044	19.20	16.85	.228	.213	.237	.247	.199	.206
		Roots	.7143	.3571								
2	.000168	Tops	.7884		17.90		.138		.244		.200	
			1.2762	1.0323	19.30	16.60	.106	.122	.299	.271	.197	.198
		Roots	.6462	.3231	17.60		.178	·	.250		.220	
3	.00168	Tops	1.3519		15.70		.045		.259		.247	
			1.1269	1.2394	18.10	16.90	.046	.045	.225	.242	.232	.239
		Roots	.9034	.4517	17.10		.054		.213		......	
4	.0168	Tops	1.0000		16.78		.033		.254		.109	
			1.2750	1.1370	16.51	16.64	.028	.030	.222	.238	.138	.123
		Roots	.7219	.3609	20.98		.068		.203		.231	
Full Nutrient		Tops	1.0992		20.17		.310		.268			
			1.0750	1.0872	19.12	18.69	.297	.303	.228	.224		
		Roots	.8120		20.00		.271		.233			

Grown January 24–March 6, 1916.
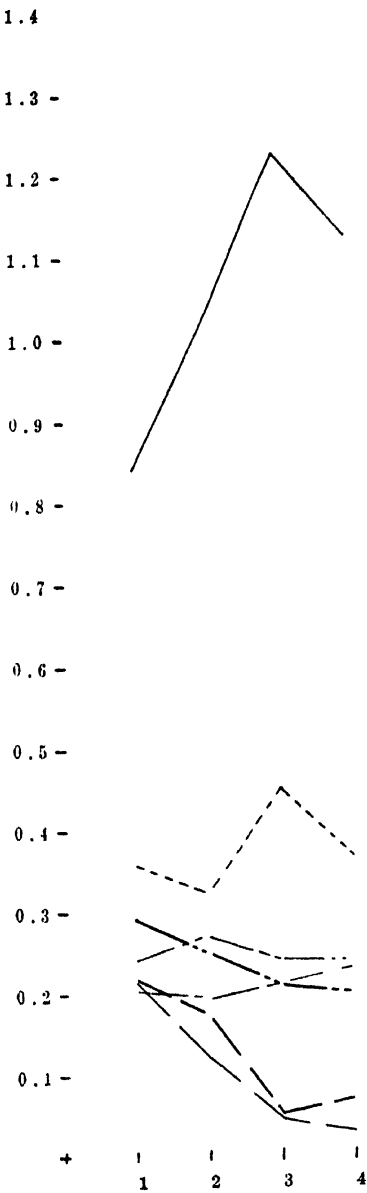
Fig. 13
Ferric Chloride
(See Table 13)

TABLE 14

Ferric chloride + Calcium Chloride

No.	Solution FeCl₃	Solution CaCl₂	Dry Weight		Mean	Percentage of Ash	Mean	Percentage of Ca	Mean	Percentage of Mg	Mean	Percentage of Fe	Mean
1	.000089	.20	Tops	.4826		18.27		1.02		.164		......	
				.4116	.4471	18.50	18.38	1.83	1.42	.137	.150	......	
			Roots	.4143	.2071	28.35		.531		.222		.100	
2	.000168	.20	Tops	.5238		17.72		1.77		.194		.080	
				.5847	.5592	16.04	16.88	1.01	1.39	.101	.147	.090	.085
			Roots	.6115	.3057	22.70		.188		.209		.03	
3	.000352	.20	Tops	.2732		20.42		2.78		.256		.370	
				.3204	.2918	20.61	20.51	3.28	3.03	.255	.255	.400	.38
			Roots	.1774	.0887	22.40		1.76	.	.692		.120	
4	.000712	.20	Tops	.5910		19.01		2.85		.212		.50	
				.3810	.4860	. . .	19.01	2.15	2.00	.262	.237	.40	.45
			Roots	.5053	.2526	31.30		1.06		.026		.02	
5	.00142	.20	Tops	.5427		16.56		1.06		.064		.36	
				.6353	.5890	17.79	17.17	1.33	1.19	.051	.058	.50	.43
			Roots	.6238	.3119	29.50		.350		.010		.16	
6	.00356	.20	Tops	2715		14.76		1.32		.097		1.18	
				.2632	.2673	17.09	15.92	1.23	1.27	.133	.115	1.02	1.10
			Roots	.2196	.1098	20.03		1.13		.018		.98	
7	.0058	.20	Tops	.1792		20.03		2.37		.256		.800	
				.2514	.2153	20.92	20.47	2.08	2.22	.297	.276	.900	.85
			Roots	.0636	.0318	29.30		1.68		.020		.200	
8	.0168	.20	Tops	.3293		17.03		.584		.246		.148	
				.4393	.3843	19.08	18.05	.460	.522	.175	.210	.120	.134
			Roots	.3565	.1783	28.04		.505		.049		.06	

Grown December 9–January 19, 1916.

Iron determined colorimetrically in this series.
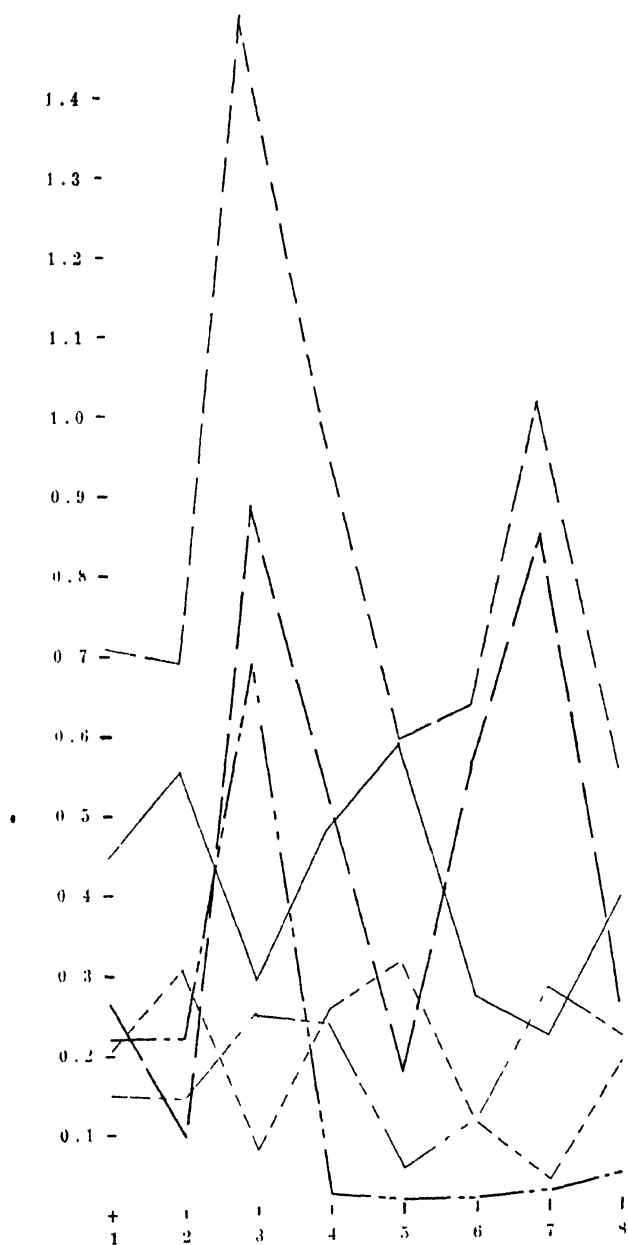
Fig. 14
Ferric Chloride + Calcium Chloride
(See Table 14)

TABLE 15

Ferric Chloride + Magnesium Chloride

No.	Solution		Dry Weight	Mean	Percentage of Ash	Mean	Percentage of Ca	Mean	Percentage of Mg	Mean	Percentage of Fe	Mean
	FeCl₃	MgCl₂										
1	.000089	.20	Tops .9650		18.48		.182		.874		.091	
			.7444	.8547	18.70	19.59	.163	.172	.833	.853	.111	.101
			Roots .6126	.3063	25.05		.204		.547		.047	
2	.000168	.20	Tops .7875		18.12		.181		.189		.210	
			.9525	.8700	18.67	18.44	.164	.172	.191	.190	... .	.210
			Roots .6816	.3408	21.40		.229		.553		.033	
3	.000352	.20	Tops .8787		15.17		.172		.218		.067	
			.7365	.8076	17.15	16.16	.137	.154	.310	.264	.073	.070
			Roots .6525	.3262	22.95		.176		.515		...	
4	.000712	.20	Tops 1.0414		16.77		.324		.116		.093	
			1.1515	1.1464	17.57	17.17	.311	.317	.119	.117	.094	.093
			Roots .4837	.2418	21.86		.258		.503		.057	
5	.00142	.20	Tops .6648		17.40		.209		.069		.233	
			.7927	.7287	16.22	16.81	.185	.197	.103	.086	.209	.221
			Roots .4627	.2313	22.12		.258		.093		.058	
6	.00356	.20	Tops 1.1639		16.50		.176		.153		.147	
			.9476	1.0557	16.10	16.30	.109	.142	...	.153	.128	.137
			Roots .3298	.1649	20.28		.433		.936		.066	
7	.0058	.20	Tops .6608		17.08		.340		.218		.040	
			.6189	.7398	16.07	16.57	.400	.370	.234	.226	..	.040
			Roots .4846	.2423	20.09		.235		.788		.050	
8	.0168	.20	Tops 1.0927		18.96		.344		1.020		.140	
			1.0824	1.0875	20.05	19.45	.391	.367	1.100	1.06	.120	.130
			Roots .6358	.3179	21.05		.177		.262		.051	

Grown January 24–March 6, 1916.
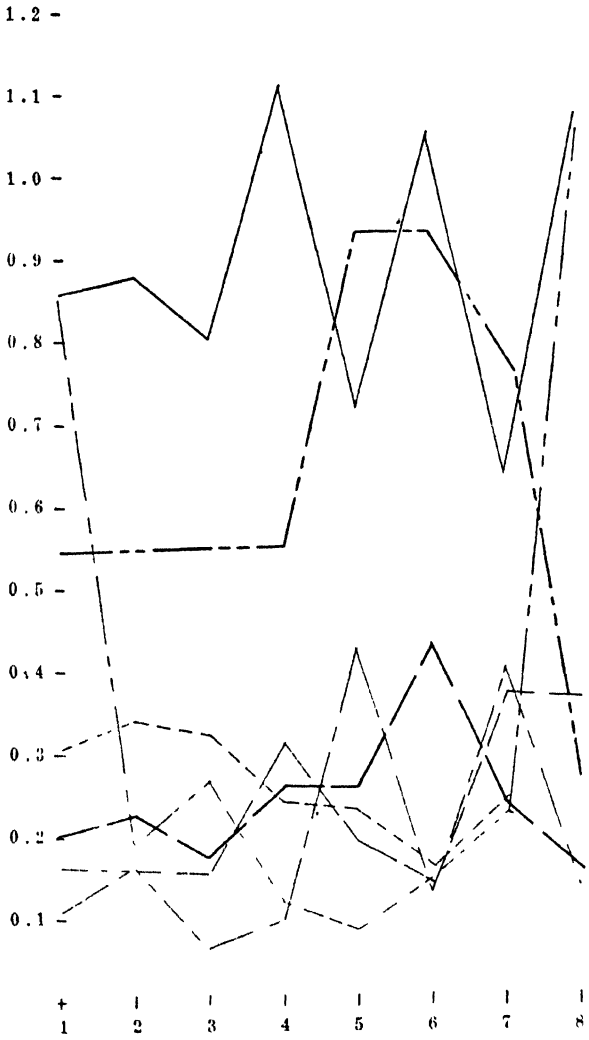
Fig. 15
Ferric Chloride + Magnesium Chloride
(See Table 15)

TABLE 16

Copper Chloride

No.	Solution CuCl₂	Dry Weight	Mean	Percent of Ash	Mean	Percent of Ca	Mean	Percent of Mg	Mean	Percent of Fe	Mean	Percent of Cu	Mean
1	.000038	Tops .4611		25.60		.425		.194		.120		......	
		Roots .4692	.4651	23.60	24.60	.420	.412	.191	.192	.201	.160	......	
2	.000079	Tops .2492		20.20		.455		.716		.155		......	
		Roots .3242	.2867	24.12	22.16	.563	.509	.723	.719	.221	.188	......	
3	.00015	Tops .3887		24.50		.312		1.10		.114		.....	
		Roots .4198	.4042	25.30	24.90	.361	.336	.90	1.00	.0261	.070	......	
4	.00031	Tops .2744		18.45		.150		1.43		.040		.001	
		Roots	.1372		18.45		.150		1.48		.040		
5	.00047	Tops .2581		22.00		.176		1.35		.214		.002	
		Roots .2344	.2462	18.10	20.05	.102	.139	1.02	1.18	.094	.154	.002	.002
6	.00063	Tops .0785		19.10		.254		3.77		. . .			
		Roots .0700	.0742	18.21	18.65	.425	.339	5.10,	4.43	.248	.248	.005	.004
7	.00079	Tops											
		Roots	No growth.										
8	.00198	Tops											
		Roots	No growth.										
9	.00392	Tops											
		Roots	No growth.										
Full Nutrient		Tops 1.1234		19.20		.311		.213					
		1.0268	1.0751	21.00	20.10	.241	.276	.199	.206				
		Roots .7210		18.99		.299		.216					

Grown March 9–April 20, 1916.
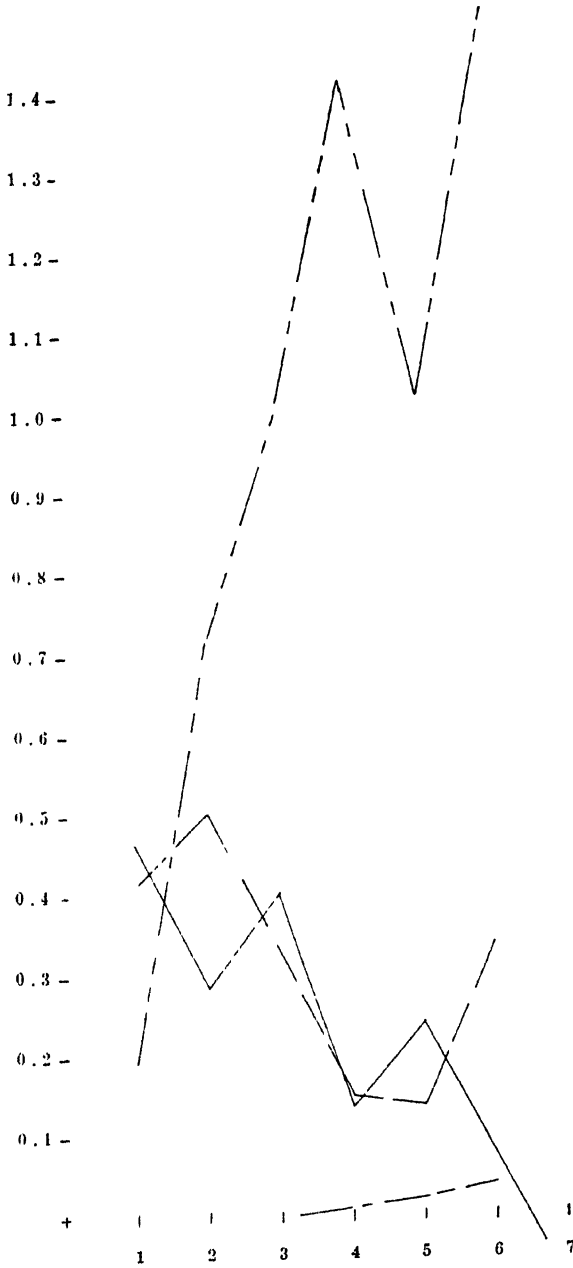
Fig. 16
Copper Chloride
(See Table 16)

TABLE 17

Copper Chloride + Ferric Chloride

No.	Solution CuCl₂	Solution FeCl₃		Dry Weight	Mean	Percentage of Ash	Mean	Percentage of Ca	Mean	Percentage of Mg	Mean	Percentage of Fe	Mean	Percentage of Cu	Mean
1	.0000094	.0000087	Tops	.4661	.4743	20.52	18.76	.0163	.014	.126	1.41	.059	.049	……	.001
				.4826		19.00		.0122		1.550		.039		……	
			Roots	.5597	.2988	17.95		.131		.336		.059		.002	
2	.0000283	.0000263	Tops	1.1519	1.0609	20.30	19.20	.197	.193	.321	.341	.038	.038	……	
				.9700		18.10		.190		3.610		.039		……	
			Roots	.9855	.4927	18.90		.070		.180		.056		.002	
3	.0000472	.000042	Tops	.5505	.5552	22.49	21.54	.259	.259	1.11	1.18	.070	.069	……	
				.5600		20.60		.259		1.26		.068		……	
			Roots	.2981	.1490	20.20		.252		.71		.056		.003	
4	.000067	.000058	Tops	.4759	.4852	21.50	20.67	.375	.335	1.13	1.09	.058	.051	.001	
				.4945		19.85		.295		1.05		.044		.001	
			Roots	.1331	.0665	-12.70		1.250		1.54		.023		.007	
5	.000094	.000042	Tops	.4750	.4150	21.40	19.80	.258	.268	.860	.82	.090	.080	……	
				.3550		18.20		.269		.790		.070		……	
			Roots	.1850	.0525	11.20		.560		.68		.016		.009	

Grown April 14–May 27, 1916.

Fig. 17
Copper Chloride + Ferric Chloride
(See Table 17)

TABLE 18

Mercuric Chloride + Copper Chloride

No.	Solution		Dry Weight	Mean	Percentage of Ash	Mean	Percentage of Ca	Mean	Percentage of Mg	Mean	Percentage of Fe
	HgCl₂	CuCl₂									
1	.0000047	.0000023	Tops .1175		20.15		.674		1.21		
			.1608	.1392	21.20	20.67	.517	.595	.935	1.07	
			Roots .0869	.0434	18.65		1.220		.276		
2	.0000094	.0000047	Tops .1792		20.00		.531		.873		
			.2675	.2233	20.32	20.16	.612	.572	.942	.907	
			Roots .0846	.0423	16.71		1.410		.291		
3	.0000184	.0000094	Tops .3778		24.70		.493		.488		
			.3328	.3503	23.30	24.30	.570	.531		.488	
			Roots .0928	.0467	15.45		1.360		.211		
4	.000047	.000023	Tops .3600		21.22		.431		.834		
			.2334	.2967	23.20	22.21	.521	.471	.921	.877	
			Roots .1109	.0554	17.32		:		.361		
5	.000094	.000047	Tops .3643		22.00		.359		.737		
			.4372	.4007	20.12	21.06	.354	.356	.695	.716	
			Roots .1109	.0554	17.32				.361		
6	.000189	.000094	Tops .2385		22.30		.521		.921		
			.3105	.2745	24.71	23.50	.503	.512	.973	.947	
			Roots .1146	.0573	12.71		1.340		.333		
7	.000378	.000188	Tops .1500		21.60		.573		1.212		
			.2150	.1825	23.40	22.50	.672	.622	1.071	1.14	
			Roots .0609	.0304	12.82				.412		

Too small amounts to determine.

Grown January 24–March 6, 1916.
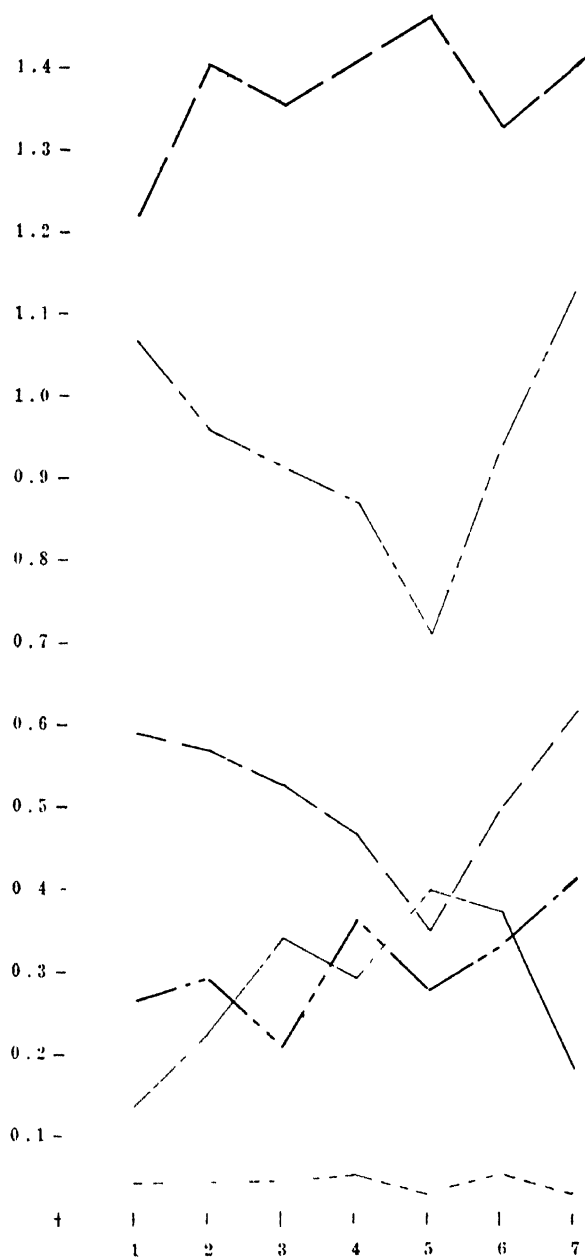
Fig. 18
Mercuric Chloride
(See Table 18)

TABLE 19

Copper Sulphate

No.	Solution CuSO$_4$	Dry Weight		Mean	Percentage of Ash	Mean	Percentage of Ca	Mean	Percentage of Mg	Mean	Percentage of Fe	Mean	Percentage of Cu
1	.0000048	Tops	.6148		22.80		.104		.331		.081		......
			.7726	.6937	21.71	22.25	.117	.110	.520	.425	.071	.076	. ..
		Roots	.4406	.2203	20.61		.153		.548		.088		.005
2	.0000094	Tops	.5394		21.42		.066		.415		.092		.
			.8462	.6928	17.50	17.46	.056	.061	.477	.446	.058	.075	
		Roots	.4512	.2256	16.40				1.010		.073		.005
3	.0000188	Tops	.4712		24.40		.177		.633		.093		
			.3128	.3920	18.90	21.65	.234	.205	.743	.688	.070	.082	
		Roots	.2948	.1474	22.50				1.170		.056		.001
4	.0000378	Tops	1.5098		22.02		.021		.210				
			1.0836	1.2967	18.90	20.46	.018	.020	2.09	2.09	.025	.025	
		Roots	.9436	.4718	18.85		.083		.215		.065		.003
5	.0000567	Tops	.7544		21.18		.105		.321		.036		
			.8022	.7783	20.44	20.81	.106	.105	.376	.348	.048	.042	
		Roots	.5265	.2632	18.10		.128		.317		.010		.004
6	.0000755	Tops	.7598		21.60		.156		.470		.058		
			.6632	.7125	20.83	21.41	.147	.151	.396	.433	.050	.074	
		Roots	.5889	.2944	19.71		.101		.377		.084		.004
7	.0000945	Tops	.3339		23.21		.374		.643		.011		
			.2439	.2889	23.60	23.45	.294	.334	.800	.721	.015	.013	
		Roots	.1567	.0783	18.00		.982		2.08				.002
8	.000189	Tops	.3267		22.61		.673		.630				
			.3786	.3526	24.80	23.70	.480	.576	.947	.788		.	
		Roots	.1630	.0815	21.40		1.430		1.450				.002
9	.000378	Tops	.2695		24.22		.530		1.31				
			.2372	.2533	22.00	23.11	.407	.469	1.34	1.32		.	
		Roots	.0696	.0348	23.80		1.53						.008

Grown April 14–May 27, 1916.
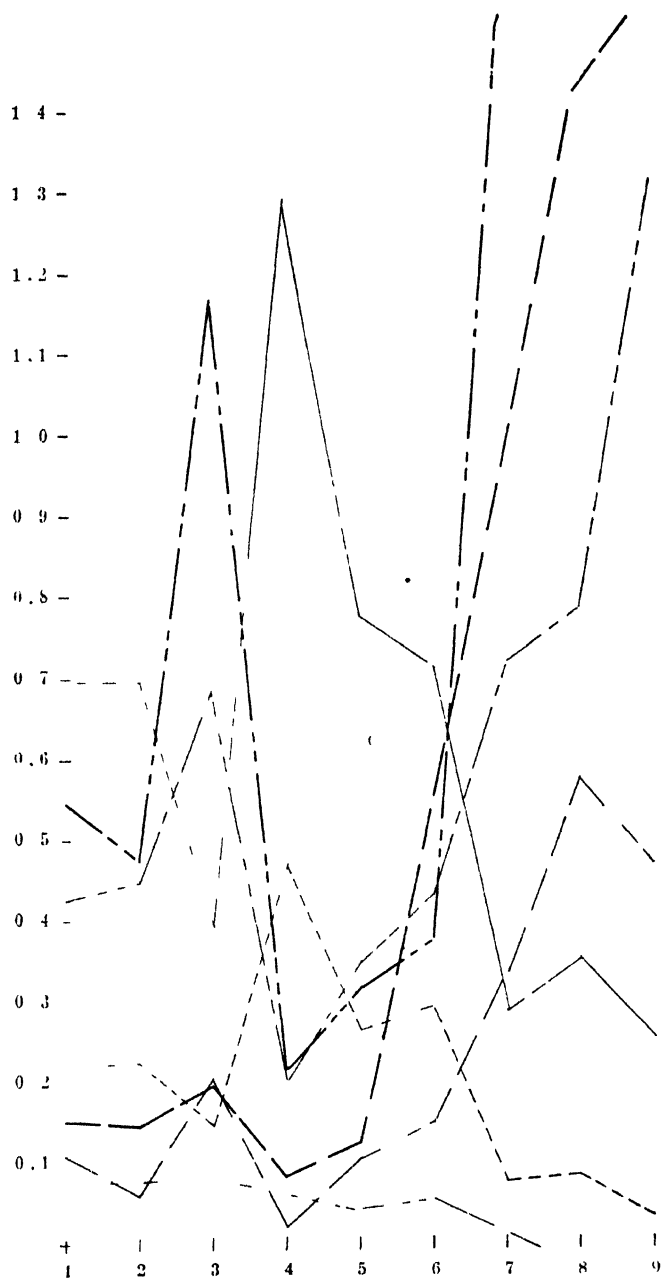
Fig. 19
Copper Sulphate
(See Table 19)

TABLE 20

Copper Sulphate + Zinc Sulphate

No.	Solution CuSO₄	ZnSO₄	Part	Dry Weight	Mean	Percentage of Ash	Mean	Percentage of Cu	Mean	Percentage of Mg	Mean	Percentage of Ge	Mean	Percentage of Cu	Mean
1	.0000047	.00000382	Tops	.5776		21.60		.151		.490		.088		.....	
			Tops	.7157	.6456	24.20	22.90	.085	.128	.462	.476	.123	.105	.....	
			Roots	.5857	.2928	19.80		.149		.299		.065		.002	
2	.0000094	.0000076	Tops	.6286		23.30		.126		.474		.061		.....	
			Tops	.4316	.5301	22.20	22.75	.114	.120	.842	.658	.078	.069	.....	
			Roots	.5316	.2658	19.20		.145		.224		.083		.005	
3	.0000142	.0000115	Tops	.6744		22.37		.226		.535		.090		.....	
			Tops	.3671	.5207	22.30	22.33	.291	.258	.927	.731	.105	.098	.....	
			Roots	.5022	.2511	16.90		.118		.457		.091		.008	
4	.0000189	.0000153	Tops	.4347		22.30		.322		.666		.105		.....	
			Tops	.4325	.4336	23.90	23.10	.312	.317	.607	.636	.102	.103	.....	
			Roots	.2375	.1187	13.37		.477		.426		.116		.011	
5	.0000378	.000036	Tops	.4959		23.30		.532		.747		.055		.....	
			Tops	.5333	.5146	24.95	24.10	.593	.561	.698	.717	.066	.060	.....	
			Roots	.2283	.1141	14.30		.513		.661		.018		.052	
6	.0000945	.000076	Tops	.4919		23.10		.794		.790		.090		.....	
			Tops	.3918	.4448	26.30	24.70	.598	.696	.755	.722	.080	.080	.....	
			Roots	.2399	.1199	19.50		.990		.636		.025		.025	
7	.0000142	.000153	Tops	.2667		26.90		.790		1.540		.071		.026	
			Tops	.3096	.2681	24.20	25.50	.808	.790	1.090	1.31	.055	.063	.019	.022
			Roots	.0924	.0462	20.60		.602		.402		.024		.043	
8	.000189	.000360	Tops	.3574		28.60		.128		.005		.047		.016	
			Tops	.3450	.3512	32.24	30.42	.189	.158	1.210	1.10	.032	.040	.017	.016
			Roots	.1039	.0519	24.80		.808		1.910		.011		.058	

Grown March 22–May 3, 1916.
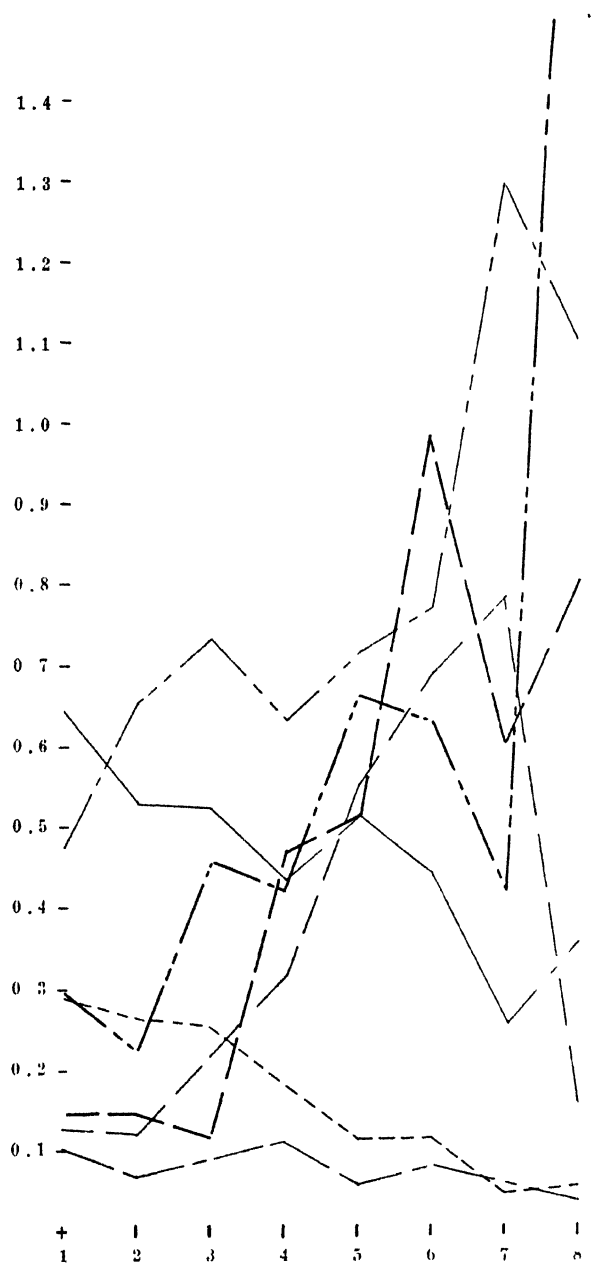
Fig. 20
Copper Sulphate + Zinc Sulphate
(See Table 20)

TABLE 21

Copper Sulphate + Ferric Sulphate

No.	Solution $CuSO_4$	$Fe_2(SO_4)_3$		Dry Weight	Mean	Percentage of Ash	Mean	Percentage of Ca	Mean	Percentage of Mg	Mean	Percentage of Fe	Mean	Percentage of Cu	Mean
1	.0000047	.0000035	Tops	.9739		23.22		.112		.168		.038			
			Tops	.9381	.9600	21.40	22.31	.127	.119	.175	.171	.029	.034		
			Roots	.6693	.3346	24.72		.157		.288		.090			
2	.0000094	.0000070	Tops	1.0281		22.50		.171		.171		.054			
			Tops	.9758	1.0019	20.60	22.55	.161	.167	.166	.168	.056	.055		
			Roots	.8194	.4097	18.12		.149		.234		.068			
3	.0000142	.0000105	Tops	1.0517		21.05		.117		.168		.057			
			Tops	1.2294	1.1405	21.61	21.33	.104	.110	.172	.170	.041	.049		
			Roots	1.0976	.5488	30.38		.103		.202		.042			
4	.0000189	.000014	Tops	.9027		22.14		.125		.156		.056			
			Tops	1.0877	.9952	20.00	21.07	.127	.126	.131	.143	.063	.060		
			Roots	.9898	.4949	23.10		.133		.245		.066			
5	.0000378	.000028	Tops	.5927		24.82		.178		.114		.037			
			Tops	.9497	.7712	23.10	22.96	.177	.177	.259	.186	.041	.039		
			Roots	.5822	.2991	20.30		.256		.237		.121		.003	
6	.000094	.000070	Tops	.5476		22.10		.194		.330		.033			
			Tops	.5050	.5263	22.30	22.20	.212	.203		.330	.041	.037		
			Roots	.1748	.0874	24.41		.520		.118		.190			
7	.000142	.000105	Tops	.4324		22.10		.206		.402		.025		.001	
			Tops	.4742	.4533	20.91	21.50	.198	.202	.442	.422	.025	.025	.002	
			Roots	.1796	.0894	21.65		.617		.289		.117		.001	
8	.000189	.00014	Tops	.4612		22.21		.267		.602		.191		.001	
			Tops	.3774	.4193	21.62	21.91	.366	.316	.675	.638	.172	.181	.002	.002
			Roots	.0744	.0387	16.40		.177		.257		.042		.002	
9	.00058	.000028	Tops	.2987		22.52		.123		1.010		.191		.007	
			Tops	.2957	.2922	23.90	23.21	.114	.118	1.240	1.12	.113	.151	.005	.002
			Roots	.0707	.0353	19.81		.129		2.290		.627			
10	.0000094	.000007	Tops	1.1573		19.96		.259		.251		.337			
		$ZnSO_4$ .0000076	Tops	.8900	1.0236	18.13	19.04	.223	.241	.197	.219	.375	.356		.063
			Roots	.7939		20.40		.100		.196		.091		.004	

Grown March 22–May 3, 1916.

Fig. 21
Copper Sulphate + Ferric Sulphate
(See Table 21)

TABLE 22

Ferric Sulphate

No.	Solution $Fe_2(SO_4)_3$	Dry Weight		Mean	Percentage of Ash	Mean	Percentage of Ca	Mean	Percentage of Mg	Mean	Percentage of Fe	Mean
1	.0000014	Tops	2.2399		17.09		.107		.098		.246	
			1.3062	1.7730	17.55	17.32	.099	.103	.113	.105	.281	.263
		Roots	1.0626		21.81		.122		.763		.315	
			......	.5313	....	21.81	......	.122	......	.763	.....	.315
2	.0000028	Tops	1.9198		20.50		.119		.070		.264	
			1.5226	1.7210	20.21	21.35	.115	.117	.072	.071	.201	.231
		Roots	.8731		25.50		.013		.145		.220	
			.4850	.6769	26.50	25.85	.020	.016	.158	.150	.286	.253
3	.0000070	Tops	1.4150		24.00		.095		.		.393	
			1.5247	1.4698	22.62	23.31	.080	.087	.102	.102	.395	.394
		Roots	.6984		31.10		.032		.263		.223	
			.7624	.7304	30.61	30.85	.041	.036	.224	.243	.277	.250
4	.000014	Tops	2.3544		20.57		.032		.089		.358	.
			2.3461	2.3502	18.90	19.73	.041	.036	.106	.097	.378	.368
		Roots	1.0361		27.20		.022		.184		.172	
			1.1861	1.1111	29.20	28.31	.011	.016	.250	.217	.178	.175
5	.00007	Tops	4.2000		14.80		.018		.072		.236	
			3.6033	3.9016	15.15	14.97	.017	.017	.073	.072	.268	.252
		Roots	.9813		25.81		.056		.134		.103	
			.9168	.9490	26.00	25.90	.077	.067	.118	.128	.129	.116
Full Nutrient		Tops	1.5682		18.33		.293		.231			
			1.5775	1.5728	19.40	18.86	.312	.302	.279	.255		
		Roots	.9776		20.40		.271		.279			

Grown April 22–June 3, 1916.
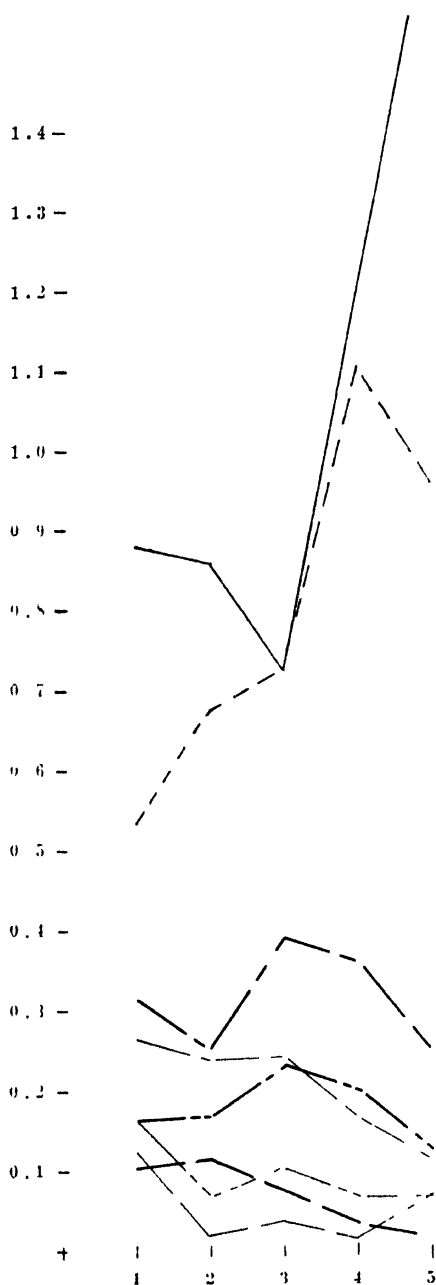
Fig. 22
Ferric Sulphate
(See Table 22)

TABLE 23

Zinc Sulphate

No	Solution ZnSO₄	Dry Weight		Mean	Percent of Ash	Mean	Percent of Ca	Mean	Percent of Mg	Mean	Percent of Fe	Mean
1	.00000767	Tops	.6718		23.00		.324		.374		.0622	
			.7541	.7129	24.04	23.52	.341	.332	.560	.467	.0587	
		Roots	.6138	.3069	17.88		.191		......		.. ..	
2	.0000131	Tops	.7164		25.30		.326		.310		.121	
			.8350	.7757	24.65	25.07	.284	.305	.386	.348	.101	
		Roots	.6009	.3004	17.20		.187		.358		.101	
3	.0000395	Tops	.6142		21.19		.372		.324		.0708	
			.8607	.7374	22.50	21.84	.316	.344	.320	.322	.0644	
		Roots	.5864	.2932	15.90		.166		.886			
4	.000153	Tops	.5109		21.90		.372		.660		.097	
			.3800	.4454	19.40	20.65	.437	.404	.760	.710	.981	.089
		Roots	.4628	.2314	20.50		.128		.423		.074	
5	.000395	Tops	.8208		20.38		.200		.321		.073	
			Lost	.4104	......	20.38	......	.200	...	.321	. .	.073
		Roots	.4432	.2216	22.30		.053		.810		.017	
Full Nutrient		Tops	1.0992		20.17		.310		.268			
			1.0750	1.0872	19.12	18.69	.297	.303	.228	.224		
		Roots	.8120		20.00		.271		.233			

Grown January 24–March 6, 1916.
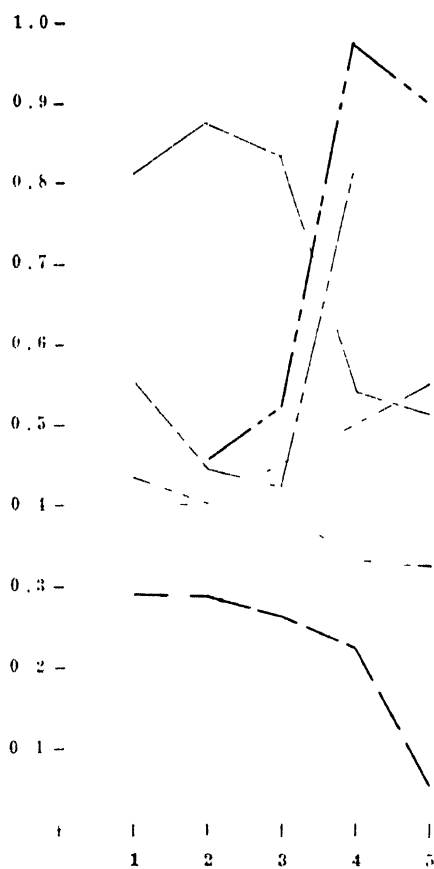
Fig. 23
Zinc Sulphate
(See Table 23)

TABLE 24

Zinc Sulphate + Ferric Sulphate

No.	Solution ZnSO₄	Fe₂(SO₄)₃	Dry Weight		Mean	Percentage of Ash	Mean	Percentage of Ca	Mean	Percentage of Mg	Mean	Percentage of Fe	Mean
1	.0000019	.0000035	Tops	1.0594		18.50		.096		.215		.031	
				1.5294	1.2944	18.70	18.60	.098	.097	.230	.222	.029	.030
			Roots	.10444	.5222	29.80		.045		.149		.037	
2	.0000038	.000005	Tops	1.5364		18.60		.149		.262		.036	
				1.4864	1.5114	16.10	17.35	.170	.159	.231	.247	.030	.033
			Roots	1.0716	.5258	31.00		.042		.184		.082	
3	.0000057	.000007	Tops	1.2300		18.10		.172		.288		.076	
				1.6150	1.4225	16.90	17.00	.124	.140	.277	.282	.064	.070
			Roots	1.1250	.5625	32.30		.068		.130		.010	
4	.0000076	.000014	Tops	2.3088		16.40		.083		.110		.065	
				2.5100	2.4094	17.00	16.70	.098	.090	.111	.110	.062	.063
			Roots	1.5623	.7812	28.00		.040		.139		.061	
5	.0000152	.000028	Tops	2.3429		15.70		.154		.151		.052	
				2.0129	2.1774	15.70	15.70	.147	.150	.158	.154	.046	.049
			Roots	1.5133	.7566	30.30		.050		.103		.069	
6	.0000379	.000070	Tops	2.0533		18.10		.160		.122		.042	
				1.5544	1.8038	16.20	17.15	.160	.160	.151	.136	.049	.045
			Roots	1.4194	.7097	25.30		.025		.243		.141	
7	.000076	.00014	Tops	1.6164		18.40		.157		.....		.0412	
				1.7228	1.6696	19.70	19.05	.144	.150	.201		.0412	.043
			Roots	1.7611	.8801	27.00		.019		.317		.128	
8	.000152	.00028	Tops	.9850		18.35		.179		.219		.045	
				1.0268	1.0029	20.00	19.17	.176	.177	.282	.250	.042	.043
			Roots	.6987	.3493	27.30		.006		.367		.....	

Grown April 24–June 6, 1916.
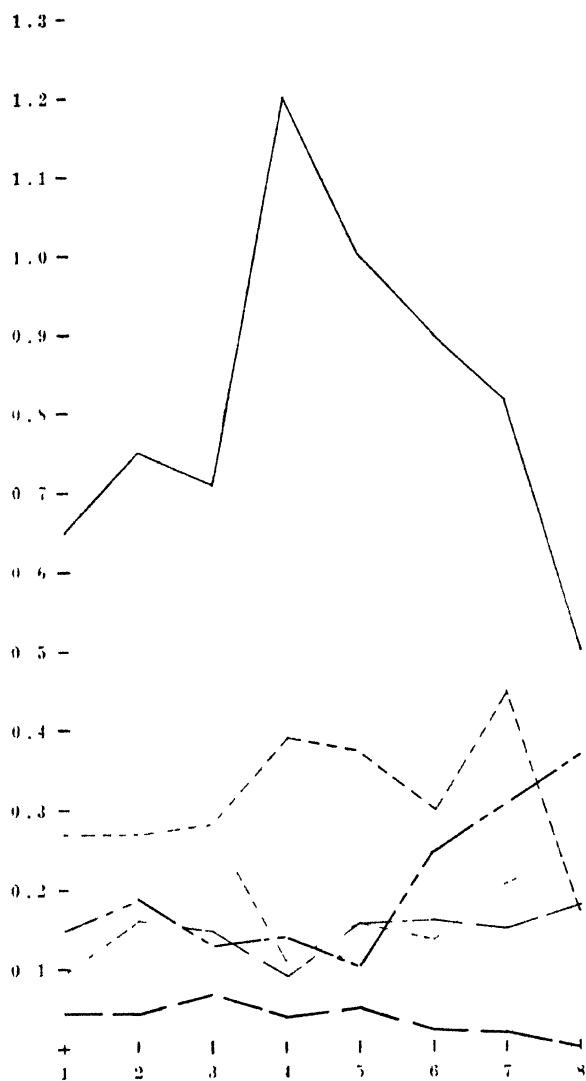
Fig. 24
Zinc Sulphate + Ferric Sulphate
(See Table 24)

TABLE 25

Mercuric Chloride + Ferric Sulphate

No.	Solution HgCl₂	Fe₂(SO₄)₃	Dry Weight		Mean	Percentage of Ash	Mean	Percentage of Ca	Mean	Percentage of Mg	Mean	Percentage of Fe	Mean
1	.0000047	.0000035	Tops	.2039		22.40		.233		.723			
				.2868	.2553	16.70	19.55	.179	.206	.513	.618		
			Roots	.0518	.0259	18.70		.840		2.670			
2	.0000094	.0000070	Tops	.2569		21.75		.123		.327			
				.3579	.3074	21.90	21.82	.138	.230	.515	.421		
			Roots	.0869	.0434	18.90		.222		2.95			
3	.0000189	.00005	Tops	.2042		16.70		.172		.371			
				.2996	.2519	19.40	18.05	.231	.201	.412	.391		
			Roots	.0896	.0448	18.13		.271		.312			
4	.000047	.00014	Tops	.2362		17.32		.192		.416			
				.2300	.2331	17.41	17.36	.183	.187	.511	.463		
			Roots	.0596	.0298	19.01		.221		2.110			
5	.000094	.0007	Tops	.2396		16.10		.420		.100			
			Lost	.2396		......	16.10	.....	.420	.....	.100		
			Roots	.0237	.0118	15.50		.151		4.580			
6	.000189	.00105	Tops	.2288		16.70		.201		.731			
				.2988	.2638	17.20	16.95	.131	.166	.807	.769		
			Roots	.0784	.0392	21.30				2.170			
7	.000378	.00210	Tops	.2184		15.61		.190		.895		.101	
				.4272	.3228	17.40	16.50	.102	.146	.550	.722	.157	.129
			Roots	.0496	.0248	18.10		.232		.738		.222	

(Column "Percentage of Fe" for rows 1–6 marked: "Not enough present to determine.")

Grown March 22-May 3, 1916.
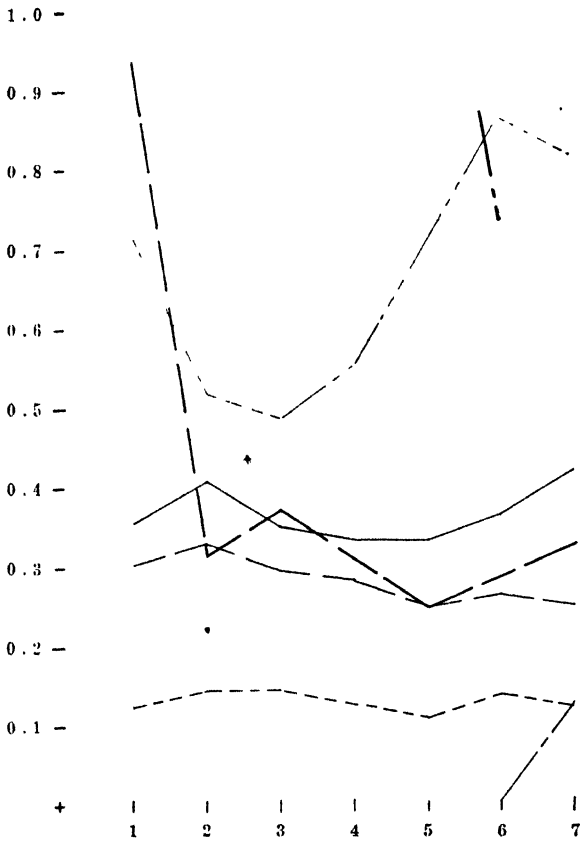
Fig. 25
Mercuric Chloride + Ferric Sulphate
(See Table 25)

TABLE 26

Mercuric Chloride

No.	Solution HgCl₂	Dry Weight	Mean	Percentage of Ash	Mean	Percentage of Cu	Mean	Percentage of Mg	Mean	Percentage of Fe	Mean
1	.0000135	Tops .4904		17.20		.141		.91		.248	
		.4967	.4935	16.71	16.95	.098	.120	.. ..	.91	.....	.248
		Roots .1493	.0746	19.31		.478		.893		.296	
2	.000066	Tops .2200		15.70		.332		1.69		.010	
		.2236	.2218	14.24	14.97	.380	.356	1.77	1.73	.017	.013
		Roots .0239	.0119	10.50		4.31		.775		.013	
3	.000135	Tops .1514		9.12		.421		1.23		.012	
		.1421	.1467	8.95	9.03	.399	.410	1.33	1.28	.013	.012
		Roots									

Grown March 14–April 24, 1916.
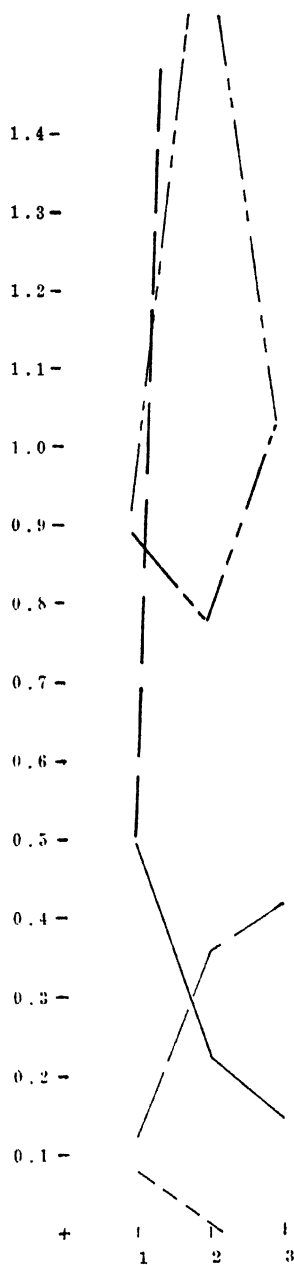
Fig. 26
Mercuric Chloride
(See Table 26)

EXPLANATION OF PLATES

PLATE 13

Appearance of plants as mounted in corks at expiration of the six weeks' growing period.

PLATE 14

No. 1. .24 M. MgCl₂ .004 M. CaCl₂
No. 2. .24 M. MgCl₂ .01 M. CaCl₂
No. 3. .24 M. MgCl₂ .02 M. CaCl₂
No. 4. .24 M. MgCl₂ .04 M. CaCl₂
No. 5. .24 M. MgCl₂ .06 M. CaCl₂
No. 6. .24 M. MgCl₂ .08 M. CaCl₂
No. 7. .24 M. MgCl₂ .10 M. CaCl₂
No. 8. .24 M. MgCl₂ .12 M. CaCl₂
No. 9. .24 M. MgCl₂ .16 M. CaCl₂
No. 10. .24 M. MgCl₂ .20 M. CaCl₂
No. 11. .24 M. MgCl₂ .24 M. CaCl₂
No. 12. .24 M. MgCl₂ .30 M. CaCl₂
No. 13. .24 M.
Control.

PLATE 15

No. 1. .30 M. MgCl$_2$ .004 M. CaCl$_2$
No. 2. .30 M. MgCl$_2$ .01 M. CaCl$_2$
No. 3. .30 M. MgCl$_2$ .02 M. CaCl$_2$
No. 4. .30 M. MgCl$_2$ .04 M. CaCl$_2$
No. 5. .30 M. MgCl$_2$ .06 M. CaCl$_2$
No. 6. .30 M. MgCl$_2$ .08 M. CaCl$_2$
No. 7. .30 M. MgCl$_2$ .10 M. CaCl$_2$
No. 8. .30 M. MgCl$_2$ .12 M. CaCl$_2$
No. 9. .30 M. MgCl$_2$ .16 M. CaCl$_2$
No. 10. .30 M. MgCl$_2$ .20 M. CaCl$_2$
No. 11. .30 M. MgCl$_2$ .24 M. CaCl$_2$
No. 12. .30 M. MgCl$_2$ .30 M. CaCl$_2$
Control.

PLATE 16

No. 1. .04 M. KCl
No. 2. .06 M. KCl
No. 3. .08 M. KCl
No. 4. .10 M. KCl
No. 5. .12 M. KCl
No. 6. .14 M. KCl
No. 7. .16 M. KCl

PLATE 17

No. 1.   .00331   M. $AlCl_3$
No. 2.   .000331   M. $AlCl_3$
No. 3.   .000132   M. $AlCl_3$
No. 4.   .000066   M. $AlCl_3$
No. 5.   .000033   M. $AlCl_3$
No. 6.   .0000165   M. $AlCl_3$
No. 7.   .0000033   M. $AlCl_3$
           Control.

PLATE 18

No. 1.   .0168   M. FeCl$_3$ .20 M. MgCl$_2$
No. 2.   .0058   M. FeCl$_3$ .20 M. MgCl$_2$
No. 3.   .00356   M. FeCl$_3$ .20 M. MgCl$_2$
No. 4.   .00142   M. FeCl$_3$ .20 M. MgCl$_2$
No. 5.   .000712   M. FeCl$_3$ .20 M. MgCl$_2$
No. 6.   .000352   M. FeCl$_3$ .20 M. MgCl$_2$
No. 7.   .000168   M. FeCl$_3$ .20 M. MgCl$_2$
No. 8.   .000089   M. FeCl$_3$ .20 M. MgCl$_2$
          Control.

PLATE 19

No. 1.   .00331   M. AlCl$_3$ .20 M. CaCl$_2$
No. 2.   .000331   M. AlCl$_3$ .20 M. CaCl$_2$
No. 3.   .000132   M. AlCl$_3$ .20 M. CaCl$_2$
No. 4.   .0000662 M. AlCl$_3$ .20 M. CaCl$_2$
No. 5.   .0000331 M. AlCl$_3$ .20 M. CaCl$_2$
No. 6.   .0000165 M. AlCl$_3$ .20 M. CaCl$_2$
No. 7.   .0000033 M. AlCl$_3$ .20 M. CaCl$_2$
        Control.

PLATE 20

No. 1.   .000094 M. $CuCl_2$ .00082   M. $FeCl_3$

No. 2.   .000067 M. $CuCl_2$ .000058 M. $FeCl_3$

No. 3.   .000047 M. $CuCl_2$ .000042 M. $FeCl_1$

No. 4.   .000028 M. $CuCl_2$ .000026 M. $FeCl_3$

No. 5.   .0000094 M. $CuCl_2$ .0000089 M. $FeCl_3$

Control.

PLATE 21

No. 1. .000378 M. CuSO$_4$
No. 2. .000189 M. CuSO$_4$
No. 3. .0000945 M. CuSO$_4$
No. 4. .0000755 M. CuSO$_4$
No. 5. .0000567 M. CuSO$_4$
No. 6. .0000378 M. CuSO$_4$
No. 7. .0000188 M. CuSO$_4$
No. 8. .0000094 M. CuSO$_4$
No. 9. .0000048 M. CuSO$_4$
Control.

PLATE 22

No. 1. .0000047 M. CuSo₄ .0000035 M. Fe₂ (SO₄)₃
No. 2. .0000094 M. CuSo₄ .0000070 M. Fe₂ (SO₄)₃
No. 3. .0000142 M. CuSo₄ .0000105 M. Fe₂ (SO₄)₃
No. 4. .0000189 M. CuSo₄ .000014 M. Fe₂ (SO₄)₂
No. 5. .0000378 M. CuSo₄ .000028 M. Fe₂ (SO₄)₂
No. 6. .000094 M. CuSo₄ .000070 M. Fe₂ (SO₄)₃
No. 7. .000142 M. CuSo₄ .000105 M. Fe₂ (SO₄)₃
No. 8. .000189 M. CuSo₄ .00014   M. Fe₂ (SO₄)₃
No. 9. .00058   M. CuSo₄ .00028   M. Fe₂ (SO₄)₂
         Control.

PLATE 22

No. 1. .0000047 M. $CuSo_4$ .0000035 M. $Fe_2 (SO_4)_3$
No. 2. .0000094 M. $CuSo_4$ .0000070 M. $Fe_2 (SO_4)_3$
No. 3. .0000142 M. $CuSo_4$ .0000105 M. $Fe_2 (SO_4)_3$
No. 4. .0000189 M. $CuSo_4$ .000014 M. $Fe_2 (SO_4)_2$
No. 5. .0000378 M. $CuSo_4$ .000028 M. $Fe_2 (SO_4)_2$
No. 6. .000094 M. $CuSo_4$ .000070 M. $Fe_2 (SO_4)_3$
No. 7. .000142 M. $CuSo_4$ .000105 M. $Fe_2 (SO_4)_3$
No. 8. .000189 M. $CuSo_4$ .00014   M. $Fe_2 (SO_4)_3$
No. 9. .00058   M. $CuSo_4$ .00028   M. $Fe_2 (SO_4)_2$
         Control.

PLATE 23

No. 1.   .0000014 M. $Fe_2(SO_4)_3$
No. 2.   .0000028 M. $Fe_2(SO_4)_3$
No. 3.   .0000070 M. $Fe_2(SO_4)_3$
No. 4.   .000014 M. $Fe_2(SO_4)_3$
No. 5.   .00007   M. $Fe_2(SO_4)_3$
Control.

PLATE 24

No. 1.   .000135   M. $HgCl_2$
No. 2.   .000066   M. $HgCl_2$
No. 3.   .0000135 M. $HgCl_2$
         Control.

VARIABILITY IN SOILS AND ITS SIGNIFI-
CANCE TO PAST AND FUTURE
SOIL INVESTIGATIONS

I. A STATISTICAL STUDY OF NITRIFICATION IN SOILS

BY

DEAN DAVID WAYNICK

VARIABILITY IN SOILS AND ITS SIGNIFI-
CANCE TO PAST AND FUTURE
SOIL INVESTIGATIONS

I. A STATISTICAL STUDY OF NITRIFICATION IN SOIL

BY
DEAN DAVID WAYNICK

It is very generally recognized that different soils vary widely as regards their physical, chemical, and biological nature. It has also been recognized among soil investigators, at least, that different samples of the same soil type taken from a comparatively limited area may show considerable variation among themselves if we apply quantitative measurements to the various constituents of the soil mass. In any small area of the size usually employed in field experiments, these variations seem to have been regarded as of such limited magnitude as to be worthy of but secondary consideration. In many instances, a single sample from such an area has been taken and the assumption made that it represented the entire soil mass of the depth to which it was taken. In other words, the soil has been considered as a constant to which no corrections need be applied. Most workers in the field of soils have been content with taking relatively few samples and regarding determinations made upon the composite of these samples as accurate within the limits of error of the experiment. That the variations between different samples taken from a small area may be of such magnitudes as to bring experimental data obtained with one or a limited number of samples into very serious question, or even to invalidate such data entirely, seems not to have been considered. It is the purpose of this paper to emphasize the importance of this phase of soil investigation as regards both past and future endeavors.

It is obviously impossible, within the limits of a single paper, to consider the variations which characterize all the constituents of any

given soil, so that the results reported at the present time relate only to one phase of the biochemistry of soils. But few attempts have been made by investigators to determine actually the magnitude of variability in those products of microörganic activity which are capable of quantitative measurement and in no instance has a mathematical interpretation been attempted with such measurements. There are but three references [1, 2, 3] in the literature, as far as the writer is aware, dealing with this phase of the biochemistry of soils, and none of them is extensive enough to be of any value as statistical studies of variability. A number of papers[4] have appeared dealing with the variation in the weight of the crop produced over different parts of an apparently uniform field. Such variations reflect the variability of the soil, serving simply as a substratum for the growth of plants, but it is evident that the variations between such measurements as those given do not depend upon the soil as the only variable factor. Any attempt to correlate the crop produced on any given soil with the chemical composition of that soil, for instance, must necessarily take into account variations in both crop and soil. In fact, it appears to the writer that any correlation which may exist between the properties of any given soil and its crop-producing power can only be worked out by the statistical interpretation of data obtained as recorded below, together with the data secured in a similar manner for the crops produced on that soil. The problem of variability in the soil itself is worthy of careful experimental study, both from the standpoint of soil investigations in themselves and from that of their possible bearing upon the problems of variability in field experiments with crops. The results of such a study, as regards nitrate production, are presented below.

METHODS

The field selected was one on the University Farm at Davis. For the three years preceding 1917, corn, Sudan grass, and grain sorghum had been grown in the order named. In 1917, the field was allowed to lie fallow and at the time the samples were taken (Oct. 20), was free of vegetation of any kind. No rain had fallen since April so that the surface soil was practically air-dry, the subsoil, however, being quite moist. The soil is classified as a silty clay loam. The particular area chosen was apparently as uniform as one could well find, being level, of uniform texture and color, and free from small local depressions of any kind.

The samples were taken at the locations as shown in figure 1, the diameter of the plot being one hundred feet. Each number in the following table represents two samples, soil and subsoil, the latter term being used for convenience in expression rather than to represent any sharp line of demarcation between the two samples taken at any given
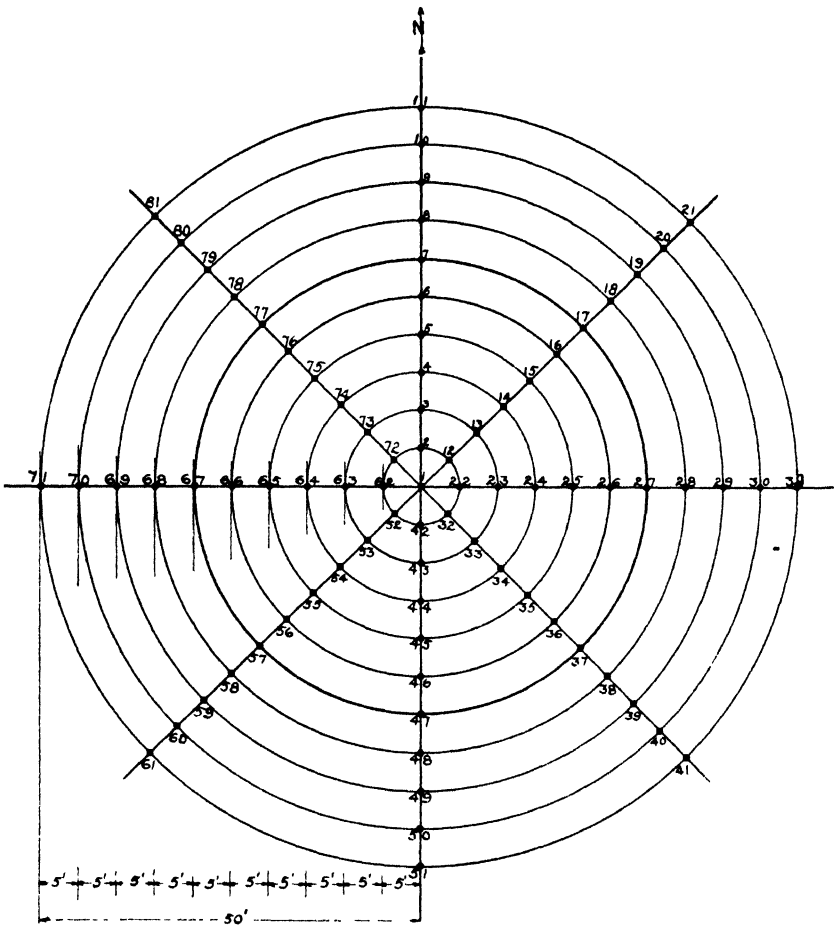
Fig. 1

place. All the surface samples were taken with a trowel to a depth of six inches, an area having a diameter of approximately six inches being included in each sample. The subsoil samples were taken with a three-inch auger to a depth of twenty-four inches and, therefore, represent the section from six to twenty-four inches in depth. All the samples were placed in sterile soil bags as soon as taken, the total amount of soil in each sample being about twice that necessary for the laboratory

determinations. Not more than twenty-four hours elapsed between the time the first sample was taken and the time all the samples were at the express office ready for shipment to Berkeley, where they arrived forty-eight hours later.

At the laboratory, the samples were allowed to air-dry for six days in the original canvas bags, this time for drying being necessary because of the moisture present in the subsoil samples. At the expiration of the six-day period all of the samples were sieved through a two-milli-meter sieve and four one hundred gram portions of each sample weighed into tumblers. One tumbler from each sample was reserved for the determination of residual nitrate; to a second no nitrogen compounds were added, and to the others two-tenths of a gram of ammonium sulfate and one gram of dried blood, respectively, these amounts having been most frequently used in nitrification experiments in this laboratory. All the tumblers were brought to an optimum moisture content by the addition of twenty cubic centimeters of sterile distilled water and placed in the incubator at 28° C for twenty-eight days. During the incubation period, the water lost was replaced at weekly intervals. At the expiration of that period, the soil was dried at a temperature of 100° C and the nitrates determined colorimetrically by the phenoldisulfonic acid method as modified by Lipman and Sharp.[5] All results are reported as milligrams of nitrate nitrogen in one hundred grams of soil.

It was not deemed necessary to make duplicate determinations on all the samples, since from previous results secured in this laboratory, the variation between duplicates, as regards nitrification studies, is small and well within the limits of the error made in the readings, which were never recorded in this study further than to one-tenth of a milligram of nitrate nitrogen. Aside from this fact, it is doubtful if duplicate determinations are of value in experiments of this kind in which the variation between the samples was found to be so large.

The amount of nitrate nitrogen produced was chosen as the criterion of variability because of the generally accepted idea that nitrate nitrogen is more directly available to plants than other nitrogen combinations and for that reason more significance may rightly be attached to the amount of nitrate nitrogen found or produced in any given soil. Then, too, small amounts of nitrate may be determined rapidly, with a very fair degree of accuracy, and moreover, are less subject to fluctuations in the duplicate determination as discussed above. The absolute accuracy of the nitrate determination by the phenoldisulfonic

acid method is not of moment in this connection, because neither very low nor very high amounts of nitrate were ever determined and all of the determinations are directly comparable one with the other, since exactly the same procedure was followed in every case.

It must be emphasized that no attempt has been made to segregate the causes of variation and the results as given are the summation of all the factors which are of importance in causing differences between samples. All the work was done in a careful manner with due attention to detail, no new or modified procedure being attempted. The results of this study, therefore, are intended to serve as a basis for interpreting the mass of data which has already been obtained by soil biologists and to emphasize the extreme importance of applying statistical methods to results secured in the future before their value as contributions to science or practice can be recognized.

CALCULATIONS[6]

The amounts of nitrate found are reported in tables 1 to 4, following, the individual determinations always being given. The mathematical treatment will be discussed briefly from the data given in table 1, the discussion being applicable to all the tables as well.

The mean as given is obtained by dividing the sum of all the determinations by the number of determinations. This figure represents, therefore, a hypothetical composite sample of all the samples taken. The deviation from the mean of any determination is found by taking the difference between the mean and the individual result. The mean deviation of a series of determinations is an expression of the average amount any single observation taken at random is likely to differ from the mean of the series. This figure may be either plus or minus, but as the sign is of no importance as regards subsequent calculations, it is not recorded but may easily be found by inspection. The standard deviation (σ) is found, after the manner usual in statistical investigations, by squaring the deviation of each determination from the mean, taking the sum of the squares thus found, dividing this figure by the total number of determinations made and taking the square root of the quotient. The percentage ratio of the standard deviation to the mean expresses the coefficient of variability (C.V.) for a given series of determinations. It is an expression of the percentage deviation on either side of the mean, within which approximately two-thirds of the determinations may be expected to lie. The

coefficient of variability of the amount of nitrate as found in the field soil is high, no less than 25.9 ± 2.1 per cent in the surface six inches and 51.4 ± 3.3 per cent in the vertical section from six to twenty-four inches. The range, therefore, within which two-thirds of the determinations may be expected to fall is from 2.0 to 3.4 milligrams in the surface soil and from 0.3 to 1.1 milligram in the subsoil. The extreme range is, of course, much greater than this, but the bulk of the determinations fall within the limits given.

A single determination, or the mean of a series of determinations can never be an absolute value and hence before any large degree of confidence can be placed in any experimental result, its degree of reliability must be known. The reliability of any determination is expressed by the probable error (E) of the determination. This figure is of such a magnitude that the probability of making an error greater than it is equal to the probability of making an error less than it, both probabilities being one-half.

The probable error (E_s) of a single determination is calculated by the formula

$$E_s = \pm.6745 \times \frac{\sigma}{\sqrt{n}}$$

where σ is the standard deviation, as given above, and n the number of determinations. Since with a single determination the $\sqrt{n}$ is equal to 1

$$E_s = \pm.6745 \times \sigma.$$

or in other words, the probable error of a single variant is equal to approximately two-thirds of the standard deviation of the series in which it lies. The probable error of the mean (E_M), is given by the formula

$$E_M = \pm \frac{Es}{\sqrt{n}} = \frac{.6745 \times \sigma}{\sqrt{n}}$$

E_M will vary as the square root of the number of determinations and thus decreases but slowly as we increase the number of determinations. The probable error $(E\sigma)$ of the standard deviation is calculated from the formula

$$E\sigma = \pm.6745 \frac{\sigma}{\sqrt{2n}}$$

and for the coefficient of variability:

$$Ec = .6745 \frac{C.V.}{\sqrt{2n}} \left[1 + 2 \left(\frac{c}{100}\right)^2 \right]^{1/2}$$

when $C.V.$ is greater than ten per cent as is the case with the results recorded below.

TABLE 1

RESIDUAL NITRATE IN SOIL AS SAMPLED

	1"–6"		6"–24"			1"–6"		6"–24"	
No.	Nitrate nitrogen Mgs.	Deviation from mean ± Mgs.	Nitrate nitrogen Mgs.	Deviation from mean ± Mgs.	No	Nitrate nitrogen Mgs.	Deviation from mean ± Mgs.	Nitrate nitrogen Mgs	Deviation from mean ± Mgs
1	2.5	0.2	1.0	0.3	42	3.0	0.3	0.6	0.1
2	2.8	0.1	1.1	0.4	43	3.4	0.7	0.7	0.0
3	3.0	0.3	1.0	0.3	44	1.8	0.9	0.5	0.2
4	2.5	0.2	1.2	0.5	45	2.5	0.2	0.6	0.1
5	3.8	1.1	1.9	1.2	46	2.1	0.6	0.5	0.2
6	2.7	0.0	1.5	0.8	47	4.0	1.3	0.8	0.1
7	3.3	0.6	1.5	0.8	48	3.1	0.4	0.6	0.1
8	3.2	0 5	1.2	0.5	49	4.4	1.7	0.4	0.3
9	2.5	0.2	1.2	0.5	50	3.5	0.8	0.5	0.2
10	2.9	0.2	1.4	0.7	51	2.3	0.4	0.7	0.0
11	3.0	0.3	1.5	0 8	52	3.1	0.4	0.6	0.1
12	2.7	0.0	0.8	0.1	53	2.3	0.4	0.8	0.1
13	1.9	0.8	1.2	0.5	54	2.3	0.4	0.6	0.1
14	3.7	1.0	1.1	0 4	55	1.4	1.3	0.8	0 1
15	3.8	1.1	0 8	0.1	56	2.5	0.2	0.5	0.2
16	3.0	0 3	1.0	0.3	57	1.8	0.9	0.5	0.2
17	2.0	0.7	0 8	0.1	58	1.7	1.0	0.4	0.3
18	2.2	0 5	1.0	0.3	59	1 3	0.4	0.5	0.2
19	2.9	0.2	1.0	0.3	60	2.0	0.7	0.4	0.3
20	3.5	0.8	0.8	0.1	61	1.5	1.2	0.4	0.3
21	3.0	0.3	1.0	0.3	62	4 0	1.3	0.4	0.3
22	4.5	1.8	0.8	0 1	63	3.0	0 3	0.3	0.4
23	3.5	0.8	0.9	0 2	64	3 0	0 3	0.5	0.2
24	3.6	0.9	0.5	0.2	65	2.0	0.7	0.4	0 3
25	1.8	0.9	0.6	0 1	66	2.0	0.7	0.5	0.2
26	3 4	0 7	0.8	0.1	67	3.0	0 3	0.6	0.1
27	3.0	0.3	2.2	1.5	68	4.3	1.6	1.2	0.5
28	1.5	0.8	0.8	0.1	69	3.2	0.5	0.4	0.3
29	2.3	0.4	0.6	0.1	70	2.6	0.1	0.5	0.2
30	2.6	0.1	0.5	0.2	71	3.5	0.8	0.4	0.3
31	1.3	1.4	0.5	0.2	72	2.7	0.0	0.3	0.4
32	3.1	0.4	0.9	0.2	73	2.4	0.3	0.4	0.3
33	2.6	0.1	0.4	0.3	74	2.0	0.7	0.4	0 3
34	2.8	0.1	0.3	0.4	75	2.1	0.6	0.4	0.3
35	1.8	0.9	0.3	0.4	76	2.6	0.1	0 6	0.1
36	1.3	1.4	0.4	0.3	77	1.5	1.2	0.6	0.1
37	1.0	1.7	0.5	0.2	78	2.6	0.1	0.6	0.1
38	4.0	1.3	0.9	0.2	79	2.4	0.3	0.9	0.2
39	3.0	0.3	0.6	0.1	80	2.2	0.5	1.2	0.5
40	3.6	0.9	0.4	0 3	81	2 0	0.7	0.8	0.1
41	3.8	1.1	0.6	0.1					

Mean 2.70±.05 0.5   0.70±.03 0.3

$$\sigma \;=\; .70\pm.04 \qquad \sigma = .36\pm.02$$
$$\text{C.V.} = 25.9\pm2.1\% \qquad = 51.4\pm3.3\%$$
$$E_M \;=\; 1.8\% \qquad = 4.3\%$$

TABLE 2

NITRATE PRODUCED FROM THE SOIL'S OWN NITROGEN AFTER TWENTY-EIGHT DAYS' INCUBATION—INCUBATED BLANKS

No	1"-6" Nitrate nitrogen Mgs	1"-6" Deviation from mean ± Mgs	6"-24" Nitrate nitrogen Mgs	6"-24" Deviation from mean ± Mgs	No.	1"-6" Nitrate nitrogen Mgs	1"-6" Deviation from mean ± Mgs	6"-24" Nitrate nitrogen Mgs	6"-24" Deviation from mean Mgs
1	4.3	0.9	1.2	0.2	42	4.5	1.1	1.2	0.2
2	2.4	1.0	1.0	0.4	43	3.8	0.4	1.4	0.0
3	2.2	1.2	1.0	0.4	44	3.0	0.4	1.2	0.2
4	1.6	1.8	0.8	0.6	45	4.0	0.6	1.0	0.4
5	2.7	0.7	1.1	0.3	46	3.0	0.4	1.2	0.2
6	4.0	0.6	1.2	0.2	47	3.8	0.4	1.3	0.1
7	1.8	1.6	1.8	0.4	48	3.3	0.1	1.2	0.2
8	3.0	1.4	1.0	0.4	49 ·	5.2	1.8	1.2	0.2
9	4.8	1.4	2.2	0.8	50	4.8	1.4	1.4	0.0
10	3.0	0.4	3.0	1.6	51	4.0 ·	0.6	2.0	0.6
11	4.2	0.8	2.1	0.7	52	3.5	0.1	1.6	0.2
12	4.5	1.1	1.5	0.1	53	3.1	0.3	0.8	0.6
13	3.1	0.3	1.4	0.0	54	4.7	1.3	1.5	0.1
14	4.6	1.2	1.5	0.1	55	3.2	0.2	0.7	0.7
15	4.2	0.8	1.1	0.3	56	4.1	0.7	1.2	0.2
16	4.2	0.8	1.6	0.2	57	1.2	1.2	2.0	0.6
17	2.4	1.0	1.5	0.1	58	3.4	0.0	1.0	0.4
18	2.8	0.6	1.1	0.3	59	2.0	1.4	1.0	0.4
19	1.8	1.6	3.0	1.6	60	3.0	0.4	2.2	0.8
20	4.8	1.4	2.2	0.8	61	1.0	2.4	0.5	0.9
21	4.8	1.4	1.4	0.0	62	1.5	1.9	0.6	0.8
22	3.5	0.1	1.5	0.1	63	1.1	2.3	0.7	0.7
23	3.7	0.3	1.4	0.0	64	1.0	2.4	1.7	0.3
24	3.0	0.4	1.2	0.2	65	3.1	0.3	1.3	0.1
25	4.2	0.8	1.7	0.3	66	5.0	1.6	1.8	0.4
26	3.8	0.4	1.8	0.4	67	3.6	0 2	1.5	0.1
27	3.1	0.3	1.6	0.2	68	2.1	1.3	2.0	0.6
28	2.8	0 6	1.4	0.0	69	4.4	1.0	1.1	0.3
29	1.8	1 4	1.5	0.1	70	3.1	0.3	1.2	0.2
30	3.5	0.1	1.5	0.1	71	5.5	2.1	1.1	0.3
31	2.8	0.6	0.4	0.0	72	3.6	0.2	1.4	0.0
32	3.2	0.2	2.0	0.6	73	3.8	0.4	1.0	0.4
33	5.2	1.6	1.8	0.2	74	3.8	0.4	0.3	1.1
34	3.3	0.1	1.2	0.2	75	5.4	2.0	1.2	0.2
35	4.5	1.1	1.1	0.3	76	3.8	0.4	1.2	0.2
36	2.8	0.6	1.4	0.0	77	4.6	1.2	1.6	0.2
37	3 0	0.4	3.7	2.3	78	1.5	1.9	1.5	0.1
38	1.7	·.7	1.1	0.3	79	5.0	1.6	1.8	0.4
39	3.8	0.4	1.2	0.2	80	3.1	0.3	1.9	0.5
40	4.0	0.6	1.7	0.3	81	3.5	0.1	1.5	0.4
41	4.1	0.7	1.0	0.4					

Mean 3.40±.08 0.9   1.40±.03 0.4

σ = 1.06±.05 σ = .50±.02

C.V. = 31.2±1.7%   = 35.7±2.1%

E_M = 2.3%   = 2.1%

TABLE 3

NITRATE PRODUCED FROM 0.2 GRAM OF AMMONIUM SULPHATE IN 100 GRAMS OF SOIL

| | 1"–6" | | 6"–24" | | | 1"–6" | | 6"–24" | |
| | Nitrate nitrogen Mgs. | Deviation from mean ± Mgs. | Nitrate nitrogen Mgs. | Deviation from mean ± Mgs. | | Nitrate nitrogen Mgs | Deviation from mean ± Mgs | Nitrate nitrogen Mgs. | Deviation from mean ± Mgs |
No.					No.				
1	6.6	1.6	1.8	1.0	42	2.1	2.9	6.3	3.5
2	4.3	0.7	3.7	0.9	43	6.2	1.2	3.0	0.2
3	8.0	3.0	2.9	0.1	44	5.2	0.2	1.0	1.8
4	6.0	1.0	3.3	0.5	45	2.3	2.7	1.2	1.6
5	4.2	0.8	3.3	0.5	46	1.8	3.2	1.8	1.0
6	6.0	1.0	2.5	0.3	47	2.5	2.5	1.5	1.3
7	5.6	0.6	3.2	0.4	48	2.5	2.5	1.2	1.6
8	5.0	0.8	4.3	1.5	49	2.0	3.0	1.2	1.6
9	5.8	0.8	4.0	1.2	50	2.3	2.7	2.2	0.6
10	5.3	0.3	3.8	1.0	51	4.8	0.2	2.3	0.5
11	4.0	1.0	1.1	1.7	52	5.5	0.5	1.7	1.1
12	5.5	0.5	3.0	0.2	53	5.4	0.4	1.7	1.1
13	5.0	0.0	2.8	0.0	54	6.5	1.5	2.8	0.0
14	4.6	0.4	2.8	0.0	55	2.3	2.7	3.2	0.4
15	5.0	0.0	3.1	0.3	56	5.2	0.2	1.2	1.4
16	6.5	1.5	3.3	0.5	57	2.2	2.6	1.5	1.3
17	4.6	0.4	5.7	1.9	58	3.6	1.4	3.2	0.4
18	5.0	0.0	4.0	1.2	59	2.2	2.6	5.0	2.2
19	6.0	1.0	4.0	1.2	60	3.5	1.5	6.0	3.2
20	5.0	0.0	2.4	0.4	61	4.2	0.8	3.5	0.7
21	5.4	0.4	2.8	0.0	62	7.2	2.2	2.0	0.8
22	6.0	1.0	3.4	0.6	63	7.3	2.3	2.4	0.4
23	6.5	1.5	3.2	0.4	64	3.7	1.3	4.1	1.3
24	4.8	0.2	2.0	0.8	65	5.7	0.7	0.2	0.0
25	5.3	0.3	2.7	0.1	66	3.8	1.2	2.5	0.3
26	5.5	0.5	5.4	2.6	67	4.9	0.1	3.0	0.2
27	4.4	0.6	4.8	2.0	68	4.8	0.2	4.0	1.2
28	7.5	2.5	4.7	1.9	69	6.8	1.8	1.0	1.8
29	7.6	2.6	2.8	0.0	70	5.8	0.8	1.3	1.5
30	6.2	1.2	1.9	0.9	71	4.0	1.0	1.0	1.8
31	4.2	0.8	2.6	0.2	72	1.8	3.2	4.0	1.2
32	5.0	0.0	3.2	0.4	73	5.3	0.3	2.3	0.5
33	6.0	1.0	3.0	0.2	74	5.8	0.8	3.8	1.0
34	4.5	0.5	2.2	0.6	75	8.2	3.2	1.5	1.3
35	4.8	0.2	1.6	1.2	76	5.5	0.5	2.5	0.3
36	4.8	0.2	1.5	1.3	77	6.2	1.2	3.1	1.3
37	4.0	1.0	2.6	0.2	78	6.0	1.0	3.0	1.2
38	5.4	0.4	2.5	0.3	79	6.3	1.3	2.6	0.2
39	5.2	0.2	2.8	0.0	80	6.0	1.0	3.5	0.7
40	6.6	1.6	2.0	0.8	81	6.0	1.0	3.2	0.4
41	6.4	1.4	2.0	0.8					
					Mean	5.00±.10	1.0	2.80±.08	0.9

$\sigma = 1.50 \pm .08$ $\sigma = 1.10 \pm .07$

C.V. $= 29.4 \pm 1.6\%$ $= 40.7 \pm 2.4\%$

$E_M = 2.0\%$ $= 3.4\%$

TABLE 4

NITRATE PRODUCED FROM 0.2 GRAM OF BLOOD IN 100 GRAMS OF SOIL

	1"-6"		6"-24"			1"-6"		6"-24"	
No.	Nitrate nitrogen Mgs.	Deviation from mean ± Mgs.	Nitrate nitrogen Mgs.	Deviation from mean ± Mgs.	No	Nitrate nitrogen Mgs.	Deviation from mean ± Mgs.	Nitrate nitrogen Mgs.	Deviation from mean ± Mgs.
1	27.0	6.0	11.0	0.3	42	7.0	14.0	20.0	9.5
2	20.0	1.0	10.0	0.7	43	18.0	3.0	10.0	0.5
3	13.0	8.0	14.0	3.3	44	18.0	3.0	13.0	2.3
4	30.0	9.0	15.0	4.3	45	21.0	0.0	12.0	1.3
5	18.0	3.0	25.0	14.3	46	13.0	8.0	14.0	3.3
6	40.0	19.0	25.0	14.3	47	18.0	3.0	19.0	8.3
7	20.0	1.0	18.0	7.3	48	20.0	1.0	12.0	1.3
8	14.0	7.0	16.0	5.3	49	21.0	0.0	18.0	7.3
9	20.0	1.0	10.0	0.7	50	20.0	1.0	17.0	6.3
10	22.0	1.0	16.0	5.3	51	24.0	3.0	9.0	1.7
11	18.0	3.0	14.0	3.3	52	21.0	0.0	10.0	0.7
12	22.0	1.0	12.0	1.3	53	27.0	6.0	12.0	1.3
13	23.0	2.0	13.0	2.3	54	32.0	11.0	22.0	11.3
14	22.0	1.0	5.5	5.2	55	32.0	11.0	7.0	3.7
15	16.0	5.0	5.6	5.1	56	20.0	1.0	18.0	7.3
16	21.0	0.0	7.0	3.7	57	27.0	6.0	10.0	0.7
17	16.0	5.0	8.0	2.7	58	27.0	6.0	4.3	6.4
18	20.0	1.0	5.0	5 7	59	14.0	7 0	3.0	7.7
19	21.0	0.0	5.5	5.2	60	30.0	9.0	20.0	9.5
20	13.0	8.0	7.7	3 0	61	22.0	1.0	4.3	6.4
21	24.0	3.0	5.0	5.7	62	23.0	2.0	10.0	0 7
22	15.0	6.0	10.0	0.7	63	24.0	3.0	9.0	1.7
23	22.0	1.0	14.0	3.5	64	14.0	7.0	4.8	5.9
24	24.0	3.0	8.0	2.7	65	29.0	8.0	10.0	0 7
25	19.0	2.0	8.0	2.7	66	21.0	0.0	10.0	0.7
26	20.0	1.0	10.0	0 7	67	28.0	7.0	6.5	4.2
27	21.0	0.0	20.0	9.5	68	23.0	2.0	1.7	0.0
28	21.0	0.0	12.0	1.3	69	19.0	2.0	5.5	5.2
29	20.0	1.0	4.4	6.3	70	16.0	5.0	3.7	7.0
30	11.0	10.0	5.9	4.8	71	17.0	4.0	2.7	8.0
31	20.0	1.0	7.4	3.3	72	27.0	6.0	4.0	6.7
32	17.0	4.0	14.0	3.3	73	30.0	9.0	5.3	5.4
33	10.0	11.0	13.0	2.3	74	28.0	7.0	24.0	13.3
34	20.0	1 0	5.0	5.7	75	25.0	4.0	10.0	0.7
35	15.0	6 0	2.4	8.3	76	22.0	1.0	12.0	1.5
36	12.0	9.0	8.5	2.2	77	28.0	7.0	4.2	6.5
37	19.0	2.0	11.0	0.3	78	24.0	3.0	9.0	1.7
38	16.0	5.0	14.0	2.3	79	22.0	1.0	12.0	1.3
39	14 0	7.0	8.0	2.7	80	17.0	4.0	7.2	3.5
40	13.0	8.0	5.7	5.0	81	30.0	9.0	21.0	10.3
41	27.0	6.0	11.0	0.3					

Mean 21.10±0.4 4.0   10.70±0.4 4.5

σ = 5.70±0.30 σ = 5.30±.30

C.V. = 27.1±1.5%   = 49.1±3.1%

E_M = 1.9%   = 4.0%

TABLE 5

Summary of Statistical Data

	Mean Milligrams	Extremes Milligrams	Standard deviation Milligrams	Coefficient of variability Per cent	Probable error of mean ± Per cent
Residual nitrate.					
Surface . .	2.70±.05	1.4–4.5	0.70±.04	25.9± 2.1	1.8
Subsoil	0.70±.03	0.3–1.2	0.36±.02	51.4± 3.3	4.3
Incubated blanks.					
Surface . .	3.40±.08	1.0 5.5	1.06± 05	31.2± 1.7	2.3
Subsoil	1.40±.08	0.1–2.2	0.50±.02	35.7± 2.1	2.1
(NH₄)₂SO₄.					
Surface .	5.00±.10	1.8–8.2	1.50±.08	29.4± 1.6	2.0
Subsoil	2.80±.08	0.2–3.2	1.10±.07	40.7± 2.4	3.4
Blood.					
Surface	21.00±.40	7.0–40.0	5.70±.30	27.1± 1.5	1.9
Subsoil	10.70±.40	1.7–25.0	5.30± 30	49 4± 3.1	4.0

Unless otherwise stated. the probable error of any value has been used directly as found in the discussion which follows so that there is simply an even chance that the results so treated fall within, or without, the limits of their respective probable errors   The effect of multiplying the probable error by two, three, or any higher number, may be found by referring to the reference cited above

Discussion of Experimental Results

To express the results in concise form. table 5 has been inserted to summarize briefly the data of the preceding tables. In the first column the means of the various series are given with their respective probable errors.   In the case of residual nitrate, 2.7 milligrams in one hundred grams of soil represent .0027 per cent of the soil or approximately 54 pounds of nitrate nitrogen per acre, considering only the upper six inches of the soil mass.   The probable error of the determination amounts to .00005 per cent of the soil so that it is an even chance that the mean of the eighty-one determinations is correct within one pound per acre.   In the subsoil, the mean of 14 pounds per acre, is within 0.6 pounds of the correct figure, on the same basis.   The extreme range amounts to 62 pounds in the surface soil and 18 pounds per acre in the subsoil, both figures being of greater magnitude than the means of the two series.   It is not possible to translate the other figures into a practical pounds per acre basis. since they represent laboratory treatments.

The extremes recorded in column two are simply the extreme determinations found in any one series. The extreme range may be determined by taking the difference between these two figures. The greatest extremes are shown by the samples to which dried blood was added, with the ammonium sulfate samples a close second. The results for any one series emphasize the very large difference found between a large number of samples treated as uniformly as possible.

It will be noted that the coefficients of variability as regards the surface samples with their various treatments differ but little among themselves, this difference amounting to only 5.3 per cent. The difference is greater with the four series in which the subsoil was used, being 15.7 per cent or nearly three times that of the surface samples. The point is again emphasized here that we are dealing with the summations of all the errors to which the samples are subject, both field and laboratory. One source of error has been allowed for, which is of a purely mechanical nature, namely, that of making the readings with the colorimeter. This error will be considered in the following section, and the coefficients of variability discussed at greater length there.

The percentage ratios given as the probable error of the mean place all the results on a comparable basis as regards the error to which the various means are subject. Attention is called to the fact that these figures are of similar magnitudes in the four series of surface samples while showing much larger differences in the subsoil samples with their various treatments.

It will be noted from tables 1, 2, and 3 that in a number of samples there was less actual nitrate nitrogen found in the subsoil samples after incubation without the addition of anything but water, or with the addition of 0.2 gram of ammonium sulphate, than was present in the soil of corresponding samples as they came from the field. This result was not anticipated and no explanation to account for this loss of nitrate nitrogen is offered at the present time. It is, however, regarded as of biochemical interest largely and not of importance as regards the variation between samples at the time the determinations were actually made.

ERROR OF THE DETERMINATIONS DUE TO THE COLORIMETER

Reference has already been made to the absolute accuracy of the nitrate determination and its bearing upon the results reported in the present paper. Aside from the absolute accuracy of the determina-

tions, it is desired to consider briefly the error in making the readings on the colorimeter due to the inability of the eye to detect small changes in the depth of color between the standard employed and the unknown solutions. All workers in soil chemistry are familiar with the Kenicott-Sargent colorimeter, so that the instrument itself needs no description here. To check the readings on the unknown solutions, a solution was prepared of the average strength of the residual nitrate determined in the first series reported. Sixteen equal volumes of this solution were taken and treated exactly as the soil extracts were treated. The average amount of nitrate nitrogen found in the sixteen portions was the same as that for the series referred to above, namely, 2.7 milligrams. The actual determinations, together with the calculated statistical constants, are reported in table 6. The probable error of the mean of sixteen samples, together with the error to which both larger and smaller numbers of samples are subject, is given in table 7. The calculations have been made by the use of the formulae already given. It is evident that the calculation of the probable error from sixteen, instead of a larger number of samples, makes it less reliable than if a larger number had been used, but since the error from this source is relatively small as compared to the error due to field sampling, it is deemed of sufficient accuracy for the purpose in hand. This error will be referred to as the laboratory error to distinguish it from the error due to sampling.

TABLE 6

COEFFICIENT OF VARIABILITY AND PROBABLE ERROR OF COLORIMETER READINGS

No	Nitrate nitrogen Milligrams	Deviation from mean + Milligrams	No.	Nitrate nitrogen Milligrams	Deviation from mean ± Milligrams
1	2.5	0.2	9	2.6	0.1
2	2.8	0.1	10	2.8	0.1
3	2.8	0.1	11	3.0	0.3
4	2.9	0.2	12	2.6	0.1
5	2.5	0.2	13	2.7	0.0
6	2.6	0.1	14	2.7	0.0
7	2.8	0.1	15	2.6	0.1
8	2.6	0.1	16	2.7	0.0
			Mean	2.7±.02	0.1

$$\sigma = .13 \pm .01$$
$$C.V. = 4.8 \pm .5\%$$
$$E_m = 0.8\%$$

It will be noted that the probable error of a single nitrate determination is 2.7 ± .09 milligrams or 3.2 per cent of the amount determined. The error for a single determination, expressed on the field samples as a percentage, is 17.4 or about 5.1 times greater than the laboratory error, even after making allowance for this error. With sixteen determinations, the probable error becomes 2.7 ± .022 milligrams or 0.8 per cent. Further, with eighty-one samples, the probable error is only 2.7 ± .009 milligrams or 0.3 per cent.

In allowing for this laboratory error in the various series reported, it is evident that it becomes relatively larger the smaller the amount of nitrate determined within the limits of the amounts found in the present study. In other words, the probable error will remain the same while the amount of nitrate determined decreases, so that the probable error will form a larger percentage of the determination. On the other hand, the probable error becomes relatively smaller as we increase the actual amount of nitrate nitrogen again within the limits of the amounts reported here. The same is true for the coefficient of variability. This increased ratio is brought out in table 8, which is simply a reconstruction of table 5, after making allowance for the laboratory error.

The coefficient of variability computed from the standard deviation (.13 ± .01 mg.) and the average amount, of nitrate nitrogen reported for the various series is given in column one. This figure is the largest for the subsoil samples in the field and the smallest for the surface samples treated with blood, the mean of the eighty-one readings being 0.7 and 21.0 milligrams, respectively, in the two cases. In the second column, the corrected coefficients of variability for the field samples are given, these being the difference between coefficients of variability before the laboratory error was allowed for and the various coefficients of variability given in column one. It will be noted that the same

TABLE 7

SHOWING THE DECREASE OF LABORATORY ERROR AS NUMBER OF DETERMINATIONS INCREASE

Number of samples	Probable error of mean Milligrams	Probable error of mean Per cent	Number of samples	Probable error of mean Milligrams	Probable error of mean Per cent
1	2.700±.087	3.2	36	.014	0.5
4	.043	1.6	49	.012	0.4
9	.039	1.1	64	.011	0.4
16	.022	0.8	81	.009	0.3
25	.017	0.7			

qualitative relations hold as between the various treatments in every case except the incubated subsoil samples which are somewhat less variable than the surface samples. With the other three series, the subsoil samples still show a much higher coefficient of variability than the surface samples, as do the samples treated with fertilizers in the laboratory in contrast with the untreated field samples. The percentage probable errors or laboratory errors are shown in column three, while the corrected figures for the field samples are given in column four.

Referring again for a moment to table 6, it is evident that the laboratory error increases as the square root of the number of determinations made, so that the mean of any number of readings on the colorimeter becomes less reliable, the fewer the number, exactly as the mean of a fewer number of samples is less accurate than the mean of a larger number. In other words, the curves of the errors of the various determinations are parallel, as will be seen by reference to figure 2. This fact must be kept in mind in considering the results given in the following section.

RESULTS OF RANDOM SAMPLINGS

It is of very direct interest to consider for a moment the accuracy of the mean of a limited number of samples taken at random. Ten surface samples are included in the first group (table 9) and sixteen in the second (table 10), since about these numbers of samples have

TABLE 8

SUMMARY OF STATISTICAL DATA AFTER MAKING ALLOWANCE FOR THE LABORATORY ERROR

	Coefficient of variability (laboratory error) Per cent	Corrected coefficient of variability Per cent	Laboratory error Per cent	Corrected probable error of mean Per cent
Residual nitrate.				
Surface	4.8± 0.2	21.1± 2.1	0.3	1.5
Subsoil	18.5± 1.0	32.9± 3.4	1.2	3.1
Incubated blanks.				
Surface	3.8± 0.2	27.4± 1.7	0.3	2.0
Subsoil	9.2± 0.5	25.5± 2.1	0.7	1.4
Ammonium sulfate.				
Surface	2.6± 0.1	26.8± 1.6	0.2	1.8
Subsoil	4.6± 0.2	36.1± 2.4	0.4	3.0
Blood.				
Surface	0.6± 0.03	26.5± 1.5	0.05	1.9
Subsoil	1.2± 0.10	48.2± 3.1	0.09	3.9

frequently been used in making up a composite sample. It is assumed for the time being that the amount of nitrate actually found in a composite sample is that expressed by the mean of any given number of samples. All the calculations have been made upon the samples reported in the tables below just as if these were the only samples taken from the area, as would be done if such a number of samples were used in an independent investigation. In this case, however, we have a much larger number of samples to check the accuracy of the results obtained with the fewer number. Table 9 gives the amounts of nitrate found in ten surface samples, numbered from forty-two to

TABLE 9

VARIABILITY OF TEN SURFACE SAMPLES TAKEN AT RANDOM

	Residual nitrate		Incubated blanks		$(NH_4)_2SO_4$		Blood	
No	Nitrate nitrogen Mgs	Deviation from mean ± Mgs	Nitrate nitrogen Mgs	Deviation from mean ± Mgs	Nitrate nitrogen Mgs	Deviation from mean ± Mgs	Nitrate nitrogen Mgs	Deviation from mean ± Mgs
42	3.0	0	4.5	0.6	2.1	1.0	7.0	10.0
43	3.4	0.4	3.8	0.1	6.2	3.1	18.0	1.0
44	1.8	1.2	3.0	0.9	5.2	2.1	18.0	1.0
45	2.5	0.5	4.0	0.1	2.3	0.8	21.0	3.0
46	2.1	0.9	3.0	0.9	1.8	1.3	13.0	4.0
47	4.0	1.0	3.8	0.1	2.5	0.6	18.0	1.0
48	3.1	0.1	3.3	0.6	2.5	0.6	20.0	3.0
49	4.4	1.4	5.2	1.3	2.0	1.1	21.0	4.0
50	3.5	0.5	4.8	0.9	2.3	0.9	20.0	3.0
51	2.3	0.7	4.0	0.1	4.8	0.7	24.0	7.0
Mean	3.00±1.7	0.6	3.90±.15	0.6	3.10±.31	1.3	17.00±.89	3.7
σ	0.80±0.12		0.70±.10		1.50±.22		4.70±.63	
C.V.	26.7±4.3%		17.9±2.7%		48.4±3.9%		24.7±3.8%	
E_M	5.7%		3.8%		10.0%		5.2%	

fifty-one, inclusive. It will be noted that these samples are taken in a straight line (see fig. 1), while the sixteen samples are taken indiscriminately over the area. Considering the residual nitrate alone, it is seen that the mean of the ten samples is 0.30 milligrams above the mean of the total number of samples. Further, the probable error of the mean is increased from ± .05 milligram to ± .17 milligram or, in terms of the probable error, the chances are about 3 to 1 that the difference between the two results is a significant one.* The coefficients of variability are very nearly the same in the two instances.

* The probable error of the differences between two results is calculated from the formula:

$$\text{Probable error of difference} = \sqrt{E_1^2 + E_2^2}$$

In the incubated samples, the probable error of the difference between the samples is 0.50 ± .17 milligrams, for the samples to which ammonium sulfate was added 1.90 ± .31 milligrams, and for dried blood 4.00 ± .97 milligrams. It is worthy of note that the probable error of the differences between eighty-one samples, to which ammonium sulfate was added, and the ten samples given above is no less than 6 to 1.†

The coefficient of variability of the ten samples is greatly increased,

TABLE 10

VARIABILITY OF SIXTEEN SURFACE SAMPLES TAKEN AT RANDOM

No	Residual nitrate		Incubated blanks		(NH₄)₂SO₄		Blood	
	Nitrate nitrogen Mgs	Deviation from mean ± Mgs	Nitrate nitrogen Mgs	Deviation from mean ± Mgs	Nitrate nitrogen Mgs	Deviation from mean ± Mgs	Nitrate nitrogen Mgs	Deviation from mean ± Mgs
1	2.5	2.0	4.3	1.0	6.6	2.2	27.0	8.0
3	3.0	0.5	2.2	1.1	8.0	3.6	13.0	6.0
7	3.3	0.8	1.8	1.5	6.6	2.2	20.0	1.0
9	2.5	0.0	4.8	1.5	5.8	1.4	20.0	1.0
30	2.6	0.1	3.5	0.2	6.2	1.8	11.0	8.0
34	2.8	0.3	3.3	0.0	4.5	0.1	20.0	1.0
37	1.0	1.5	3.0	0.3	4.0	0.4	19.0	0.0
40	3.6	1.1	4.0	0.7	6.6	2.2	13.0	6.0
42	3.0	0.5	4.5	1.2	2.1	2.3	7.0	12.0
46	2.1	0.4	3.0	0.3	1.8	1.6	13.0	6.0
49	4.4	1.9	5.2	1.9	2.0	2.4	21.0	2.0
53	2.3	0.2	3.1	0.2	6.4	2.0	27.0	8.0
57	1.8	0.7	1.2	2.1	2.2	2.2	27.0	8.0
59	1.3	1.2	2.0	1.3	2.2	2.2	14.0	5.0
60	2.0	0.5	3.0	0.3	3.5	0.9	30.0	11.0
72	2.7	0.2	3.6	0.3	1.8	2.6	27.0	8.0
Mean	2.50±.14	0.6	3.30±.17	0.9	4.40±.35	1.9	19.00±1.1	6.0
σ	0.80±.10		1.00±.12		2.10±.26		6.70±.08	
C.V.	34.4±4.5%		30.3±3.9%		47.7±6.4%		35.2±4.6%	
E_M	5.6%		5.2%		7.9%		5.8%	

being 48.4 ± 3.9 per cent. On the other hand, it happens that the incubated blanks vary even less than the eighty-one samples, the coefficients of variability being 17.9 ± 2.7 per cent and 31.2 ± 1.7 per cent respectively. It is seen from these results that very wide variations may be found when only ten samples are used in making a composite sample and that that number of determinations is by no means enough to be an accurate measure of the actual nitrate nitrogen content when the variations are of the magnitudes of those noted above.

Turning for a moment to the results given in table 10, we find that

† For table of odds to aid in estimating the significance of differences between two results, see Batchelor and Reed, Jour. Agr. Res., vol. 12, pp. 265–266, 1918.

the probable error of the difference between the mean of the sixteen samples taken purely at random, and the entire number of determinations made, to be .20 ± .15 milligrams, with a coefficient variability of 34.4 ± 4.5 per cent as contrasted with 25.9 ± 2.1 per cent for the total number. The difference between the number of samples considered here and the total number is not significant with the incubated blanks, but with the ammonium sulfate samples the probable error of the difference between the means is 0.66 ± .33, and with dried blood 2.0 ± 1.1. The chances are somewhat less than 2 to 1 that the differences between the sixteen samples here considered and the total eighty-

TABLE 11

EFFECT OF DISTANCE UPON THE VARIABILITY IN SAMPLING—RESIDUAL NITRATE

| | Five foot radius | | | Twenty-five foot radius | | | Fifty foot radius | |
No	Nitrate nitrogen Milligrams	Deviation from mean Milligrams	No	Nitrate nitrogen Milligrams	Deviation from mean Milligrams	No	Nitrate nitrogen Milligrams	Deviation from mean Milligrams
2	2.8	0.4	6	2.7	0.3	11	3.0	0.5
12	2.7	0.5	16	3.0	0.6	21	3.0	0.5
22	4.5	1.3	26	3.4	1.0	31	1.3	1.2
32	3.1	0.1	36	1.3	1.1	41	3.8	1.3
42	3.0	0.2	46	2.1	0.3	51	2.3	0.2
52	3.1	0.1	56	2.5	0.1	61	1.5	1.0
62	4.0	0.8	66	2.0	0.4	71	3.5	1.0
72	2.7	0.5	76	2.6	0.2	81	2.0	0.5

Mean 3.20±.14   0.5   2.40±.14   0.4   2.50±.19   0.6
  σ   0.60±.10   0.60±.10   0.80±.13
C.V. 18.7±3.3%   25.0±4.5%   32.0±5.8%
E_M 4.4%   5.8%   7.6%

one samples are significant. It is evident that calculations made from the mean of sixteen samples are of a higher degree of accuracy than when only ten samples are used, but the number is still too few to give results of a high order of reliability, and could by no means be taken as truly representative of the entire area under consideration.

Other numbers and other groupings may be selected and the magnitude of their means and their accompanying probable errors and coefficients of variability computed from the data reported in tables 1 to 4.

EFFECT OF DISTANCE UPON VARIABILITY

To determine whether or not the distance apart the samples were taken is a factor of importance in sampling, the arrangement given in table 11 has been made. The results shown in the table are for residual

nitrate in the surface samples only. The first group of determinations, from numbers two to seventy-two, inclusive, by intervals of ten, were recorded from samples lying within a radius of five feet of number one. The mean of the eight readings is 3.20 ± .14 milligrams or 0.5 ± .15 milligrams above the mean for the whole number of samples. The coefficient of variability is, however, relatively low.

The second group of determinations from numbers six to seventy-six, varying as those of the group above, are of the samples on the circle with a radius of twenty-five feet from the center. The mean of this group of eight determinations is 2.40 ± .14 milligrams or 0.3 ± .15 below that of the established mean as already given. The coefficient of variability in this case is nearly the same as for the total of eighty-one samples, however.

The last group of determinations represents the nitrate found in the samples taken as the fifty-foot radius. The mean of the eight determinations is 2.50 ± .20 milligrams; 0.70 ± .24 milligrams and .10 ± .24 milligrams. In two cases, the differences are significant; in the third, the probable error is greater than the difference and holds between the most widely separated samples taken on the twenty-five and fifty-foot radii. Even though only eight samples are considered in any one group, the conclusion seems justified that the distances apart samples are taken is of little importance, except in so far as their distribution be uniform over the area to be sampled. A small area of an apparently uniform field may lead to very erroneous results, as evidenced by the high figures obtained for the mean of the determinations made upon the samples on the five-foot radius. It is, of course, taken for granted that we are dealing in every instance with a field suitable for experimental work and hence not marked by changes in the soil apparent to the eye.

Estimate of the Number of Samples Required for any Given Degree of Accuracy[7]

It is very desirable to know just how many samples it is necessary to use to secure the degree of accuracy deemed desirable for the work in hand. By the use of the probable error and the standard deviation found from any representative number of samples, an estimate of the number of samples which will give a lower or higher degree of accuracy than the number used may be computed. For example, in the case of

the residual nitrate determinations, we have seen that the mean of the eighty-one samples amounted to 2.70 milligrams, with a probable error of $\pm .05$ milligrams and the standard deviation of the series 0.70 gram. As already stated, the probable error of the mean is expressed as

$$E_{\mathrm{M}} = \frac{.6745 \times \sigma}{\sqrt{n}}$$

1 Laboratory Error
2 Residual Nitrate 6"-24"
3   "   "   1"-6"
4 Incubated Blanks 6"-24"
5   "   "   1"-6"
6 Ammonium Sulfate 6"-24"
7   "   "   1"-6"
8 Blood   6"-24"
9   "   1"-6"

mg Nitrate Nitrogen

No of Samples
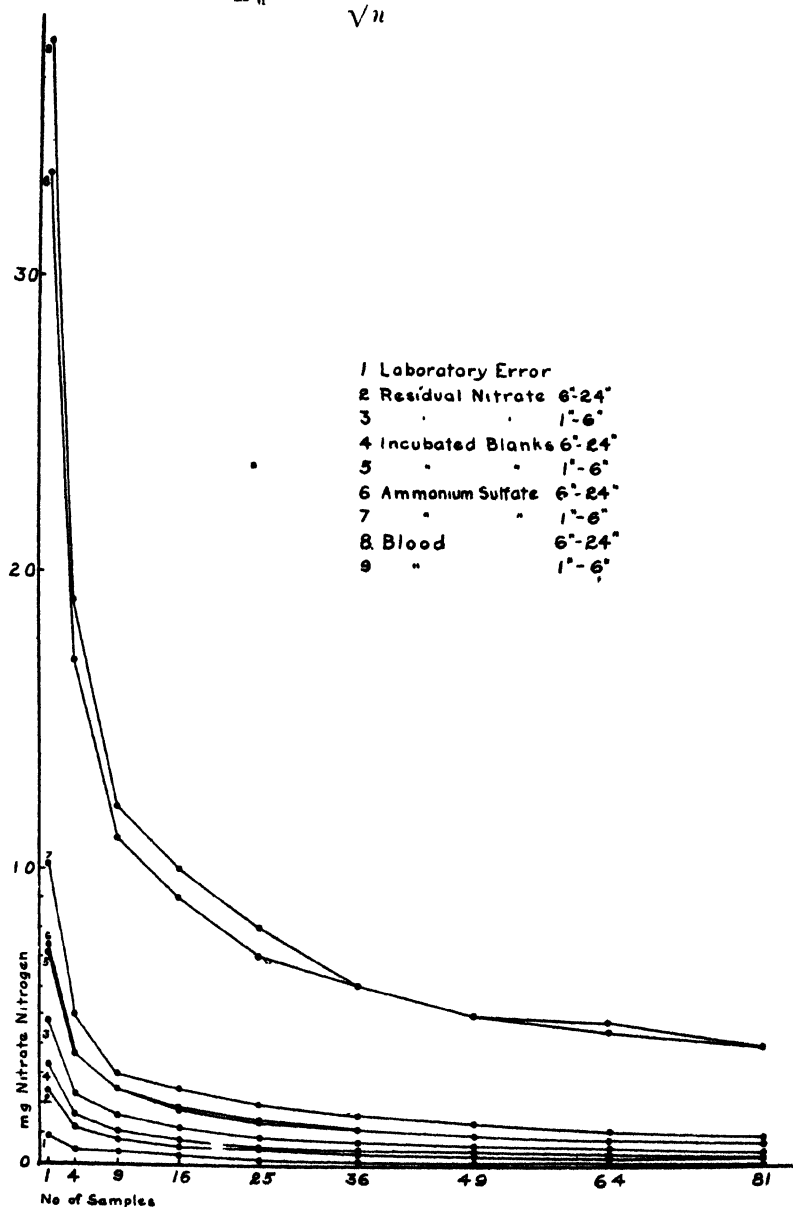
Fig. 2

and since the standard deviation in this instance is 0.7 gram, hence

$$E_M = \frac{.6745 \times 0.70}{\sqrt{n}}$$

We can make E_M of any dimension desired and since our method of determining nitrates allows of direct determinations only to 0.1 milligram, we will use this number for the probable error of the mean of the desired number of determinations so that

$$\pm 0.10 = \frac{.6745 \times 0.70}{\sqrt{n}}$$

from which $n = 22$. It must be remembered, however, that the laboratory error increases as we decrease the number of determinations in the same manner as the probable error of our sampling, so that this increased error must be taken into account in estimating the number of samples necessary to ensure any desired degree of accuracy. Referring to table 7, we find that the probable error of making the readings on the colorimeter for twenty-five samples is .017 milligram or very nearly .018 milligram for twenty-two samples, so that for a probable error of 0.1 milligram we have

$$\pm 0.1 = \frac{.6745 \times 0.13}{\sqrt{n}}$$

and $n = 1$. Thus twenty-three samples are sufficient so that the probable error in the mean is 0.10 milligram. The taking into account of the laboratory error involves an extra calculation, which, for all practical purposes, may be avoided by the use of a table, such as shown by table 12 (represented graphically in figure 2), which has been calculated from the data given in tables 1, 2, 3, and 4, after the manner already outlined. It will be noted that this table is of limited range and accounts for numbers of samples less than eighty-one, but may be extended for a range greater than the one given if desired. The approximate number of samples may be readily found after the following manner. It is desired to determine the number of ammonium sulfate samples necessary to be taken to ensure the same degree of accuracy as for twenty-three residual nitrate samples, of which the probable error of the mean was calculated to be ± 0.10 milligram. By reference to table 12, it is found that about eighty-one samples are required without taking the laboratory error into account. This error is .009 milligram (table 7) for eighty-one samples, an amount less than one per cent of the error which we are allowing for and hence

negligible, for all practical purposes, when the probable error of the sampling is of as great a magnitude as 0.1 milligram. It must be recognized that the mean of the number of samples so calculated may be found to have a greater or less probable error in practice so that a greater number of samples than calculated should be taken. This relation has already been brought out in the previous section, where it was shown that the fewer the samples, the less representative of the total area they became. By an inspection of table 12, it is evident that the number of samples necessary to secure the degree of accuracy which we established for the residual nitrate samples must be very greatly increased, when we are dealing with ammonium sulfate or blood treated samples.

TABLE 12

PROBABLE ERROR WITH VARYING NUMBERS OF DETERMINATIONS

Number of samples	Residual nitrate		Incubated blanks		Ammonium sulphate		Blood	
	1″–6″	6″–24″	1″–6″	6″–24″	1″–6″	6″–24″	1″–6″	6″–24″
	Mgs.	Mgs.	Mgs.	Mgs.	Mgs.	Mgs.	Mgs.	Mgs.
1	.47	.24	.71	.33	1.01	.74	3.8	3.5
4	.23	.12	.37	.16	.5	.37	1.9	1.7
9	.16	.08	.25	.11	.3	.25	1.2	1.1
16	.12	.06	.18	.08	.25	.19	1.0	0.9
25	.09	.05	.14	.06	.20	.15	.08	0.7
36	.08	.04	.12	.05	.17	.12	0.6	0.6
49	.07	.035	.10	.048	.14	.10	0.5	0.5
64	.06	.03	.09	.04	.12	.09	0.48	0.45
81	.05	.03	.08	.03	.10	.08	0.4	.04

It will be remembered that throughout the discussion, we have considered the probable error of the mean of any given series of samples directly, so that we have but an even chance that the mean for any given number of determinations made will be of significance. It is usual to consider about three times the probable error as a significant difference between two given means, hence if we are to establish this standard as regards the number of samples taken, we must increase all the figures given by three times.* It is obvious that such a number of samples in the case of dried blood, for instance, would be far beyond practical limits as regards the making of the determinations. The chances are that the use of a fewer number of samples means a low degree of reliability for any determinations made. If soil biologists are to continue to make beaker tests with fertilizers, the results must be interpreted from this viewpoint.

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* By multiplying the probable error found by 3.17 the chances are thirty to one that a difference greater than the figure so found is significant.

While we are not justified in using the results obtained from laboratory treatments as direct criteria of what will happen in the field, it is probable that greater variability will be found in field plots which have been subject to treatment with fertilizers than in the normal soil to which no fertilizers have been added, especially when the fertilizer is of such a complex nature as dried blood.

It must further be emphasized that the figures as given above apply only to the soil under discussion; each soil with the treatment applied must be considered as a unit in a statistical study. It is evident that a standard established for the residual nitrate, for instance, will not hold for the nitrate produced from a one per cent application of blood. The exact correlation between the various laboratory treatments and between those treatments and results secured in the field is reserved for discussion in a future publication.

REPRESENTATIVE AND COMPOSITE SAMPLES

It is evident from the results already presented in various groupings that a representative sample of any soil is a purely hypothetical quantity whose constituents may only be determined indirectly. It is also evident that determinations reported from only one sample of a given area are practically worthless, when the errors to which it is subject are of the magnitudes shown above. Composite samples made up from a small number of single samples are of little more value. Not until enough samples have been taken to enable the proper calculation of the probable error of the mean of a given number of samples is the making of a composite sample justified, since the results obtained from working with such a sample are of very limited value unless the error to which the composite sample, itself, is subject, can be determined.

It seems, therefore that the use of the word composite as relating to soil samples is only justified when the variations to which the individual samples are subject are known and enough samples taken to establish the error to which the composite, as a mean of all the samples, is liable. The magnitude of the error which is liable to creep into the determinations due to imperfect mixing in a composite sample is no doubt worthy of consideration, but since its value is undetermined, it has been assumed that a composite actually represents the mean of all the samples taken. Just how reasonable such an assumption may be remains for future investigations to bring out.

General Discussion

It has already been stated that the area under discussion was of very limited extent and as free from apparent variations as any area is likely to be. Also, that the treatment and climatic influences had all tended toward a state of biologic equilibrium as regards nitrate production in this particular soil. With this viewpoint in mind, the importance of applying a statistical interpretation to results obtained from working with a given soil type obtained under conditions much less favorable, becomes doubly important. It is not at all improbable that variations several times greater than those reported will be found in many instances and the number of samples deemed sufficient in this case must be increased to obtain any considerable degree of accuracy It is possible that areas more uniform than the one used will be found, but it is hardly probable that such will be the case.

While the present paper deals only with the production of nitrates, not only the variability of the products of microörganic activities, but the chemical constituents of any soil should be studied in a similar manner to determine just how reliable past results in soil investigations may be. It is beyond question that before we can have faith in future results, we must apply the principles outlined. 'A study of the problems of nitrogen fixation in the soil, which is to be as complete and as carefully controlled as possible, is now under way at this station. Statistical methods are to be applied to the variations in the total nitrogen, total carbon, and nitrates, at least, in two representative soils under observation before a treatment of any kind is applied. In other words, the experimental areas to be used are being standardized as carefully as possible, making due allowance for field variations in the constituents noted above. Further, the field errors due to variations between the samples must not be greater than the experimental error due to the laboratory manipulations, since the increases (or decreases) to be measured are themselves of small magnitude. To be sure, this method of procedure takes much extra time and energy, but it must be employed before the results of any treatments which are made may be correctly interpreted or recommendations based upon the experimental results safely made. It is hoped that some of the results of these preliminary studies may be ready for publication in the not far distant future.

As regards the effect of seasonal variation upon the accuracy of results which may be obtained at one season of the year upon those secured at another period, no data are as yet available which are extensive enough to warrant any conclusion. It is evident that if a "representative" sample must be found from time to time whenever new work is undertaken, the procedure would become very laborious. The prediction is made that the probable error of the mean as found in any one sampling will be very nearly the same for other samplings taken at other seasons of the year, so that it will only be necessary to make a composite sample of a previously determined number of individual samples and apply the probable error, as previously found, to the results obtained.

The segregation of the causes of biologic variation in the determinations as made, is of importance. Some evidence has already been presented showing the increased variability due to laboratory treatment. Variations in moisture present under incubator conditions, the change in the medium due to the addition of various fertilizers, and the mixing of the fertilizer with the soil are all causal factors in the variations between samples as regards the amount of ammonia, nitrate, or similar compounds finally measured. We are attempting, in this laboratory, to determine the extent, and to limit as much as possible, the variations due to manipulation. In the field the only possible cause contributing to increased variability is the method of sampling, and from unpublished results to be reported later the differences between different methods of sampling are of but little moment in a study of field variability. Variations between field samples may only be allowed for as already outlined and are no longer serious sources of error when once recognized.

There can be no doubt that much of the work done in the past, as regards nitrification at least, is open to very serious question in the light of the results herein reported. Just how much of it can be retained can only be determined by a careful checking of the actual determinations made, taking into account the error due to sampling and to the laboratory manipulations. If the data reported in table 4, for instance, be arranged in any proper order, it will be found that nearly any desired series of results may be secured, agreeing closely in their relative range with any series of results obtained from plots or tumbler treatments which have been reported by various investigators. Individual investigations are not referred to here in detail, since their large number precludes their discussion in the limited space

of this paper. It is beyond question that the soil is an extremely variable quantity and that its variability must be measured and taken into account before any determinations made upon it become of value.

Summary

A study of variability as regards nitrate production of eighty-one samples of soil taken from a limited area of an apparently uniform soil, is reported. Both surface and subsoil samples were taken. The nitrate present at the time of sampling, the nitrate produced from the soil nitrogen, from ammonium sulphate, and from dried blood were determined. Statistical methods were applied for the interpretations of the results. The following conclusions seem justified from the data presented:

1. The variability of the field samples of soil, even from an apparently uniform area of limited extent, is high and is a factor of extreme importance in an estimation of the reliability of any series of results.

2. The variability of the samples treated as in the tumbler method for nitrification studies is increased over that found for the nitrate produced in the field.

3. Subsoil samples vary more in the field, and when treated with fertilizers in the laboratory, than surface samples taken from the same area. No explanation of this fact can be offered at the present time.

4. A single sample of any soil is of little value as regards determinations which may be made upon it.

5. A limited number of samples as ten or sixteen, are subject to wide variations and can only be used when the results are to be interpreted as having a low degree of accuracy.

6. A composite sample may be considered as of value only after the probable error to which it is subject is known and this can only be determined by the use of a large number of individual samples.

7. The distance apart samples are taken is of little importance as long as the samples are uniformly distributed over an area which is apparently uniform.

8. In the light of these results, the conclusion seems inevitable that much of the past work done, as regards nitrification at least, must be critically examined to determine the degree of reliability, if any, it may have.

Attention is called to the fact that variations in other products of microörganic activity and in the chemical constituents of different samples of the same soil may be as large or even larger than those found in the present study; and that a much more comprehensive study of variability than the one herein reported is now being carried out.

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DOES CaCO₃ OR CaSO₄ TREATMENT AFFECT THE SOLUBILITY OF THE SOIL'S CONSTITUENTS?

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UNIVERSITY OF CALIFORNIA PUBLICATIONS

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In 1850, Thompson[1] showed that when soil is shaken with a solution of sulphate of ammonia, calcium sulphate is brought into the solution. Using this observation as a basis, Way[2] proceeded, in a classical investigation, to study the nature of the phenomenon. He found that when the calcium sulphate goes into solution as observed by Thompson, there is an amount of base in the form of calcium and of other bases set free in the solution equivalent to the amount of ammonium base which is absorbed by the soil. From this fact and his observation that clay carries the constituent which thus reacts with the sulphate of ammonia, Way argued that there exist in the clay certain "double silicates" of the alkalies and alkali earths with aluminum, which are the active bodies in the reaction under consideration. He never proved that such double silicates actually exist in the "clay" of the soil, but believed them to be present there because his artificially prepared double silicates of calcium and aluminum, of sodium and aluminum, and others, behaved toward salt solutions like the clay, and lost their absorptive and reactive powers, like clay, on ignition. In contradistinction to Liebig's view that the precipitation by soils of salts from solution constitutes merely a physical phenomenon, Way believed that the Thompson experiment, which typifies such soil-salt phenomena, represents, really, a chemical reaction. Way's view became generally

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[1] Thompson, H. S., On the absorbent power of soils, Jour. Roy. Agr. Soc., vol. 11, p. 68, 1850.

[2] Way, J. T., On the power of soils to absorb manure, *ibid.*, vol. 11, p. 313, 1850, and vol. 13, p. 123, 1852.

accepted and has been taught and is still very largely taught in the agricultural colleges today under the subject of "fixation" or "exchange" of bases in soils. The presence in the soil of double silicates or zeolites was thus assumed by soil investigators, and Hilgard gave the idea much prominence in connection with his methods and hypotheses on soil analysis. Further, the idea served as a basis for the use, by Lawes and Gilbert, of sodium sulphate and of magnesium sulphate in connection with the application of fertilizers to their experimental plots with the end in view of setting free potassium, from its silicate combinations in the soil, for use by the plant.

All of this has led to the statement, universally employed by authors of texts on soils, that the application of lime and gypsum to soils results, among other changes wrought by them, in the making "available" of potassium and other ions* of a similar nature. As recently as 1907, Hall and Gimingham[3] adduced experimental evidence on the interaction between clay and ammonium sulphate, which appeared to mark that reaction as one obeying the mass law, thus seemingly lending support to the validity of Way's hypothesis. Hall and Gimingham's evidence was soon shown by Cameron and Patten[4] to be incomplete, however. They demonstrated that the mass law does not hold when a wider range of concentrations than that employed by the former investigators is tested and a new hypothesis was necessary to explain it. This was furnished by Van Bemmelen, who proved that absorption by soils was closely parallel to that by colloids which he had studied, and which may be explained by the formula $y/m = Kc^{1/n}$ in which y is the amount absorbed by a quantity m of the absorbent, c the concentration of dissolved substance when equilibrium is attained, and K and n are constants depending on the nature of the solution and the adsorbent. Such a formula has since been shown to hold for absorption of phosphates by Prescott[5] and for absorption of ammonium salts by Wiegner.[6] In accordance with this conception of the soil as a colloid-containing body, the colloidal particles possess the power of holding ions which are adsorbed from salt solutions and give such ions up with relative facility to new solutions containing other ions for which they are substituted.

* In this case and throughout this paper, the term "ion" is not used in the literal sense. It is not intended to convey the idea that the authors believe that a given ion by itself is absorbed or set free, for we are actually inclined to the belief that in these cases, as in absorption by plants, not ions, but compounds, are absorbed as units

3 Hall, A. D., and Gimingham, C. T., The interaction of ammonium salts and the constituents of the soil, Trans. Chem. Soc., vol. 91, p. 677, 1907.

4 Cameron, F. K., and Patten, H. E., The distribution of solute between water and soil, Jour. Phys. Chem., vol. 11, p. 581, 1907.

This idea has, however, been confused with the zeolitic hypothesis from which, in some respects, it is quite distinct. Due to both concepts, the teaching is still largely in vogue that CaCO₃ and CaSO₄ possess as one function in soils a power to set potash and other bases free from their insoluble combinations. In spite of the general acceptance of this view, however, some practical agronomists have called it in question and it seems necessary to determine if the hypothesis and the laboratory experiments used in support thereof are valid. Briggs and Breazeale[7] have recently made an attempt to answer definitely the question as to whether or not lime or gypsum applied to soils does affect the potassium content of the soil solution produced by orthoclase, pegmatite, or orthoclase-bearing soils in contact with water. They checked their results by growing young wheat seedlings in the solutions produced by the treatment of the mineral or soil with lime or gypsum and water. As a result of these experiments, they conclude that the "availability to plants of the potash in soils derived from orthoclase-bearing rocks is not increased by the addition of lime or gypsum. In some instances, a marked depression of the solubility of the potash in the presence of gypsum was observed." While the authors specifically refer to "soils derived from orthoclase-bearing rocks," the statement carries the implication, owing to the stated object of their investigation, that the potash-bearing silicates of any kind in soil are not likely to be affected in solubility by the addition to the soil of lime or of gypsum. The fact that this conception is contrary to what one would expect from theoretical considerations regarding soil-solution reactions, appeared to render it desirable to investigate the subject farther. We therefore planned and executed the following experiment:

Calcium carbonate or calcium sulphate were each added to soils, and throughly mixed with them in the different cases as further indicated in the tables. The soils thus mixed were placed in pots in the greenhouse. Water was added to make optimum moisture conditions and such moisture conditions were maintained for a period of nine months. Three soils were used, viz: Oakley blow sand, Berkeley clay adobe, and a greenhouse soil, the latter having been originally made by admixing

⁵ Prescott, J. A., The reaction between dilute acid solvents and soil phosphates, Proc. Chem. Soc., vol. 30, p. 137, 1914.

⁶ Wiegner, Georg., Zum Basenaustausch in der Ackererde, Jour. Landw., vol. 60, pp. 110 and 197, 1912.

⁷ Briggs, L. J., and Breazeale, J. F., Availability of potash in certain orthoclase-bearing soils as affected by lime and gypsum, Jour. Agr. Res., vol. 8, p. 21, 1917.

barnyard manure with the Berkeley clay adobe soil. The applications of CaCO₃ and of CaSO₄ were made on March 9, 1917, and in the manner and quantities indicated in the tables. Control soils, untreated with either lime or gypsum, were, of course, included in the experiment, but were otherwise treated like the other soils. The soils in all pots were sampled three times, at considerable intervals, as shown in the tables. The samples were taken so as to represent the whole depth of the soil layer in the pot and of different parts thereof. Eight hundred gram portions of these samples, in air-dry condition, were mixed with 1600 cc. of distilled water in large bottles and allowed to digest for six days with occasional shaking during every day. After six days, the solutions were filtered through Pasteur-Chamberland pressure filters and analyzed by gravimetric or volumetric methods for the constituents named in the tables. Large enough aliquots could be employed, owing to the method which we have devised and described above for mixing the soil and water, to insure accurate results by the standard methods of analysis intended for larger quantities of the same substances. We employed no checking system by means of germinating plants, such as that used by Briggs, because (1) we do not believe that a few days' growth of plants constitutes any reliable criterion regarding any factor in plant growth, and (2) the evidence obtained by Burd, Hoagland, and Stewart has demonstrated that for plants grown to maturity, an intimate relation holds between the nature of the soil solution and absorption of nutrients by plants growing in such soil solutions in every stage of growth. In other words, we contented ourselves with trying to determine whether or not the soil solution is enriched with respect to potassium and other elements by the treatment of soil with CaCO₃ or with CaSO₄ *as indicated by the composition of the soil extracts obtained by us.* The results of the analyses of the soil extracts are shown in the subjoined tables, in which the amount of every ion sought and found in the solution is expressed in parts per million of the soil.

For the sake of greater simplicity and brevity, we shall at first discuss the tables separately.

In table 1, we see the results obtained with the Oakley soil, from which it is clear that both lime and gypsum are without effect on the amount of water soluble potassium in that soil. The latter behaves in this respect like the Oatman soil from Riverside County in this state, which Briggs and Breazeale have studied. There is little reason to believe, likewise, from the data under consideration that the water

TABLE 1. OAKLEY SOIL

Treatment: Rate per acre kilograms	Date of sampling	Fe	Ca	Mg	S	K	P
			In parts per million of dry soil				
Control	Apr. 9, '17	1.0	16	2.3	17	9.1	
500 CaCO₃	Apr. 9, '17	3.6	23	3.9	16	8.1	
1000 CaCO₃	Apr. 9, '17	3.4	31	6.9	21	10.3	
500 CaSO₄	Apr. 9, '17	1.4	32	3.1	21	9.7	
1000 CaSO₄	Apr. 9, '17	1.4	63	1.0	20	10.7	
Control	July 20, '17	1.2	13	3.6	10	7.9	6.9
500 CaCO₃	July 20, '17	2.0	27	6.7	10	7.8	5.8
1000 CaCO₃	July 20, '17	1.4	26	9.3	10	8.4	10.4
500 CaSO₄	July 20, '17	1.4	26	1.6	23	8.3	5.5
1000 Ca SO₄	July 20, '17	1.4	62	0.9	45	6.9	8.1
Control	Dec. 24, '17	1.4	24	1.3	19	8.8	6.7
500 CaCO₃	Dec. 14, '17	1.4	31	1.3	14	9.1	7.2
1000 CaCO₃	Dec. 24, '17	1.5	34	1.3	13	9.9	6.1
500 CaSo₄	Dec. 24, '17	1.0	44	1.7	30	7.3	6.7
1000 CaSO₄	Dec. 24, '17	0.6	61	1.3	64	8.0	6.3

TABLE 2. ADOBE SOIL

Treatment Rate per acre kilograms	Date of sampling	Fe	Ca	Mg	S	K	P
			In parts per million of dry soil				
Control	Apr. 23, '17	0.7	17	0.7		7.4	
1000 CaCO₃	Apr. 23, '17	0.7	25	1.4		12.8	
1000 CaSO₄	Apr. 23, '17	0 8	50	1.1		9.6	
Control	July 20, '17	0.7	32	2.1	32	9.7	7.2
1000 CaCO₃	July 20, '17	0.7	34	4.2	31	15.0	7.8
1000 CaSO₄	July 20, '17	0.7	78	2.1	124	12.4	7.5
Control	Jan. 2, '18	1.6	47	2.6	32	8.3	5.6
1000 CaCO₃	Jan. 2, '18	1.6	46	2.6	31	8.8	6.1
1000 CaSO₄	Jan. 2, '18	1.0	84		146	10.0	5 7

TABLE 3. GREENHOUSE SOIL

Treatment Rate per acre kilograms	Date of sampling	Fe	Ca	Mg	S	K	P
			In parts per million of dry soil				
Control	Apr. 20, '17	7.8	83	9.3	40	14.4	
500 CaCO₃	Apr. 20, '17	15.5	112	19.5	42	15.3	
1000 CaCO₃	Apr. 20, '17	8.3	115	25.5	49	25.4	
500 CaSo₄	Apr. 20, '17	7.0	157	17.8	91	20.4	
1000 CaSO₄	Apr. 20, '17	7.8	210	6.7	106	27.0	
Control	July 20, '17	4.5	86	8.6	51	23.8	14 0
500 CaCO₃	July 20, '17	7.8	91	20.6	86	25.0	12.3
1000 CaCO₃	July 20, '17	5.6	104	24.3	82	38.6	12.3
500 CaSO₄	July 20, '17	4.5	129	9.3	130	28.2	11.4
1000 CaSO₄	July 20, '17	4.2	162	5.2	165	34.8	10.1
Control	Jan. 12, '18	11.9	93	3.9	55	12.8	20.2
500 CaCO₃	Jan. 12, '18	9.8	128	5.0	76	15.4	19.6
1000 CaCO₃	Jan. 12, '18	9.8	142	5.4	76	32.0	18.4
500 CaSO₄	Jan. 12, '18	9.7	176	4.0	182	17.7	16.7
1000 CaSO₄	Jan. 12, '18	9.8	171	4.3	219	22.4	17.1

soluble phosphorus and the water soluble sulphur in that soil have been affected by $CaCO_3$ and the first by $CaSO_4$. The calcium content of the solution is affected by both $CaCO_3$ and $CaSO_4$, as would be expected, but which does not necessarily have to occur. On the other hand, the water soluble iron content of the soil appears possibly to be slightly-affected by the $CaCO_3$ treatment, at least in the first sampling; and the magnesium content of the water extract shows, it seems to us, very distinct accretions, through the $CaCO_3$ applications, in the first and second samplings. The effect seems to have disappeared, however, by the time the third sampling was made and a new equilibrium is probably established. On the contrary, gypsum seems to depress the amount of water soluble magnesium in the soil solution of the Oakley soil. This appears to be definitely true by the time the period of the second sampling has been reached, and less definitely in the period of the first sampling with the larger gypsum application. Just as the tendency to increase in amount in the soil solution through the instrumentality of the treatment seems to characterize both the ions, magnesium and iron, in the periods up to and including the second sampling, a reverse tendency is manifested by these ions by the time of the third sampling. In the soils treated with $CaCO_3$, there is a definite decrease in magnesium, in the solution, in the period named and the iron content of the same soil solutions seems to decrease simultaneously. Yet the other ions do not seem to have been affected in that way in the same period, but have either remained stationary or have shown increases. These rather marked changes evidenced by the figures of the second and third samplings are even more distinct in the cases of the other soils, to which reference will be made below.

In the Berkeley clay adobe soil, the data for which are given in table 2, conditions are quite evidently not the same as in the Oakley soil. While the potassium content of the latter soil's solution remained unaffected by the application of either $CaCO_3$ or $CaSO_4$, that of the former soil seems to us to be definitely increased by both $CaCO_3$ and $CaSO_4$ in the first two samplings and by $CaSO_4$ alone in the last sampling. The greater effect in that direction is clearly induced, however, by $CaCO_3$. The iron content of the soil solution in the clay adobe soil remains entirely unaffected by the treatment which is accorded the soil. The phosphorus content of the soil solution affected by $CaCO_3$ may, perhaps, be slightly increased in both the second and third samplings, but the data do not give us leave to be certain on

that point. The calcium and sulphur content of the soil solution behave
as one would expect without experiment in the clay adobe soil treated
with $CaSO_4$, but the calcium content of the same soil treated with
$CaCO_3$ is affected to a small degree in some cases and not at all in
others. The magnesium content of the clay adobe soil solution behaves
similarly to that of the Oakley soil solution, but the increases due to
$CaCO_3$ treatment of the soil are not as large in the former as in the
latter. Again $CaSO_4$ seems to be without effect in that direction. In
general, the behavior of the clay adobe soil solution, as judged by our
analyses, parallels that of the Oakley soil solution in the third samp-
ling, a condition of equilibrium, and, in general of a more dilute
solution, having been attained. That does not hold, however, for the
soil treated with $CaSO_4$. In general, therefore, the results obtained by
us with the clay adobe soil, among other things, show a lack of agree-
ment between our results and those of Briggs and Breazeale regarding
the effect of $CaCO_3$ and $CaSO_4$ on the potassium content of the soil
solutions in question.

Coming finally to a consideration of the greenhouse soil, we find in
table 3 some very interesting data, and the most definite of any sub-
mitted in all the tables, inasmuch as the changes due to soil treatment
are so much larger than those characterizing the other soils. Con-
sidering the data for potassium first, we find that marked increases in
the amount of that ion in the solution of the greenhouse soil are
induced by the larger application of $CaCO_3$ and by both the smaller
and larger applications of $CaSO_4$. Moreover, even the smaller appli-
cation of $CaCO_3$ seems to induce the solution of definitely larger
amounts of potassium than those found in the solution of the untreated
greenhouse soil. In the periods of the first two samplings, the iron
content of the soil extract seems to have been increased by the $CaCO_3$
applications, but not by the $CaSO_4$ applications. Moreover, the smaller
$CaCO_3$ application seems to have been much more effective in that
direction than the larger application. By the time of the third
sampling, the effects just mentioned appear to have vanished, and in
fact, it is possible that they have been supplanted by a depression in
the amount of iron in the soil extract. The general direction taken
by the effects of the soil treatment on the calcium content of the soil
extract is what one would expect *à priori*. The results indicate, how-
ever, the inaccuracy of the method of determination considered, in the
large, since the relations between the $CaCO_3$ and $CaSO_4$ applications
in small and large amounts do not maintain themselves constant

This holds, of course, for the other soils as well as for the greenhouse soil, indeed, more markedly so. The phosphorus content of the soil extract is certainly not increased, in the two determinations made, by the treatment of the soil under consideration. In fact, while it is difficult to appraise it as such, there seems to be a slight depression in the amount of the phosphorus present in the soil extracts of the treated, as against those of the untreated soils. The magnesium is affected in the greenhouse soil similarly to the manner in which it was influenced in the other soils, but, as in the case of the potassium, the results are much more emphatic. It is quite evident that large amounts of magnesium go into solution through the influence on the soil of $CaCO_3$ throughout the period of the experiment, but especially in the periods of the first two samplings. $CaSO_4$, on the other hand, only increases the amount of magnesium when employed at the smaller application and then only in the period of the first sampling. With the larger application of $CaSO_4$, in the first sampling and with both applications in the second sampling, there seems to be evidence of a depression in the magnesium content of the soil extract. In the third sampling, the $CaSO_4$ treated soils seem to behave like the control and furnish another instance of the phenomenon noted above in the case of the other soils. The sulphur content of the soil extract is more markedly affected by the treatment in question in the case of the greenhouse soil than any other constituent thereof which we have determined. That is, perhaps, not surprisingly so in the case of the $CaSO_4$ treatment, but it is to be particularly remarked how very great such increases are even with the $CaCO_3$ treatment. Unlike the cases of the other constituents of the soil extract, moreover, that of the sulphur shows the effect of treatment even at the third sampling.

GENERAL DISCUSSION

From a general survey of our results, a few facts stand out clearly. Of the seven ions which we have determined in the extracts of the soils treated with $CaCO_3$ or with $CaSO_4$, all, with possibly one exception—phosphorus—are affected by the treatment in one or more of the three soils, in the directions either of increase or decrease in amount in the soil solution. The ions are not all affected by the treatment in any one soil, however. It appears that the nature of the soil minerals, as well as the organic matter content of the soil, and hence probably the partial carbon dioxide pressures, are important factors in deter-

mining how $CaCO_3$ or $CaSO_4$ will affect the soil reactions and the precipitation or the greater solution of given ions in any soil. This marked disparity between the nature of soil reactions and their results in different soils, seems to have been but slightly appreciated, if at all, among soil investigators. We therefore find, on the one hand, the iterated and reiterated statements in our text-books respecting the effect that lime or gypsum, or both, exert on the available potash supply in the soil solution; and, on the other hand, such statements as that by Briggs and Breazeale to which we have made reference above, which deny directly or inferentially the effectiveness of lime and gypsum, in that direction, for a certain soil or a certain mineral; and through the absence of comparison with other soils imply the denial of the existence of such effects in general. As is freqently the case in all matters, the truth lies between these extreme views. Potassium from the soil minerals is rendered soluble in greater quantity than normally by applications to the soil of both $CaCO_3$ and $CaSO_4$ in some soils, but not in others. Of the three soils which we have studied, two seem to us to show clearly the former and one the latter effect.

Working also with only one soil (Dunkirk clay loam), Lyon and Bizzell,[8] by the indirect method of studying drainage water from lysimeters, and by the possibly direct method of studying absorption by plants, showed, prior to the work of Briggs and Breazeale, that liming of soils does not increase the potassium content of the drainage water, or of plant substance. But, it should be noted too, that in other respects their results are also at variance with ours. For example, they found that the application of lime to soil (to be sure it was CaO and not $CaCO_3$) did not increase, and in general, actually depressed the amount of calcium in the drainage water and hence probably, though not necessarily, in the soil solution; whereas we have found the calcium content to be higher and distinctly so in all soil extracts but one from soils treated with either lime or gypsum regardless of the soil's nature. In our opinion, these apparent disagreements are really only manifestations of the marked differences characterizing the physical-chemical systems which we call soils in equilibrium with water. When we consider soils as such systems, dynamic and not static in nature, and in addition apply to them the Van Bemmelen formula for absorption by colloids, it is not difficult to understand the

8 Lyon, T. L., and Bizzell, J. A., Calcium, magnesium, potassium and sodium in the drainage water and from limed and unlimed soils, Jour. Amer. Soc. Agron., vol. 8, p. 81, 1916.

discrepancies in the reactions between different soils and CaCO₃ or CaSO₄, which we have been studying. While thus we are in apparent disagreement with the principle of the indirect results of Lyon and Bizzell regarding the effect of lime on the calcium content of the soil solution, we are not actually so. On the other hand, we are in actual agreement with them as regards the effect of calcium applications on the magnesium content of the soil solution. In all soils studied by us, we find increases of magnesium in the soil solution, due to CaCO₃ applications, but this does not imply that the same would hold for all other soils. Again, we are in agreement with the indirect results of Lyon and Bizzell regarding the sulphur content of the soil solution as affected by lime applications in the case of the greenhouse soil, but not in the case of the clay adobe soil, and probably not in the case of the blow sand.

If we may repeat, therefore, we are apparently forced to conclude, from the results of our experiments and from such comparisons of them with those of others as we can make, that no general idea of the effect of CaCO₃ or of CaSO₄ on the potassium content of any other ion in the soil solution can be adduced from any one soil or from any one general kind of soil. In some soils, large accretions of soluble potassium to the solution may be obtained by CaCO₃ or by CaSO₄ applications; in others no increases may be obtained. This may hold for any ion, but does not preclude the probability that some ions may be rendered soluble in larger amounts by CaCO₃ in any soil. *Whether or not the ions which are rendered soluble in greater amounts by the application to the soil of CaCO₃ or CaSO₄, or both, are also available in such larger amount to the plant roots is another question,* an affirmative answer to which does not necessarily follow from such an answer to the question which we are discussing here. It is to be noted from our results, also, that the time of the year at which ions are sought in the soil solution, or at least the period elapsing between the application of CaCO₃ or of CaSO₄ to the soil and the sampling of the latter, are important factors in determining the results of one's findings and cannot be overlooked in any such investigations.

In anticipation of queries which may arise from readers of the foregoing discussion, we desire to make very clear and emphatic the following general statement. We do not believe that all of the data given by us in the tables are significant, because we appreciate the large error which probably attaches to our method of obtaining the soil extract and of analyzing it. Our calculations are such, therefore, as

not to be dependent, in any large degree, upon the significance of any isolated portion of our data. The table which we hold to be most significant is table 3 and the two chief conclusions which we desire to draw from our work are (1), that a soil may be distinctly affected, as regards the solubility of its constituents through its treatment with CaCO₄ or with CaSO₄; and (2), that this is not necessarily so, however, and may hold for one soil and one constituent in one case, and not in another, depending on the nature of the physical-chemical systems dealt with and upon the composition of the soil mineral complexes. In these two conclusions from our experiment, one can find a reconciliation of the two diametrically opposed views with regard to the effects of CaCO₃ and CaSO₄ on soils and we offer our discussion as a contribution to such a reconciliation.

Summary

From experiments to determine how CaCO₃ and CaSO₄ affect the water soluble iron, calcium, magnesium, potassium, sulphur, and phosphorus in soils as determined by ordinary water extractions, the following outstanding conclusions were drawn:

1. All soils do not behave alike when treated with CaCO₃ or with CaSO₄. They should not be expected to do so, considering their mineral composition, the law of chemical equilibrium, and the nature of colloid action in soils. With this conception as a basis, the conflicting statements in our literature on the effect of CaCO₃ and CaSO₄ on the soluble potassium supply in soils may easily be accounted for and each view may be regarded as correct under certain circumstances.

2. Potassium was found to be rendered more soluble by CaCO₃ and by CaSO₄ applications in clay adobe soil and in a greenhouse soil made therefrom, but not in a blow sand soil.

3. The soluble calcium content was increased in all soils studied by CaCO₃ or CaSO₄ applications. This does not prove that the same will hold true for all other soils.

4. The soluble magnesium content of all soils studied was increased by CaCO₃ treatment. It seems to have remained unaffected or even to have been depressed by CaSO₄ treatment in all but one case in each, the Oakley and the greenhouse soil with the small gypsum application.

5. The soluble iron content was probably increased in the solution of the greenhouse soil by the treatment in question. It seems also to

have been so increased for a time in the blow sand, but not in the clay adobe soil.

6. The soluble sulphur content was increased in the solution of the greenhouse soil by $CaCO_3$ applications and probably also in that of the blow sand, due to similar treatment.

7. The phosphorus content of the solutions of the three soils studied seems to have remained unaffected by the treatments accorded the soils. The indications are, however, that a slight depression in the amount of the water soluble phosphorus may have resulted from the $CaCO_3$ or the $CaSO_4$ applications in one case. In this case also no generalization is attempted.

8. It seems that our current teachings on soils and plant physiology should be corrected with these results as a basis.

Transmitted June 4, 1918.

AN INVESTIGATION OF THE ABNORMAL
SHEDDING OF YOUNG FRUITS OF THE
WASHINGTON NAVEL ORANGE*

BY

J. ELIOT COIT AND ROBERT W. HODGSON

INTRODUCTION

The genus *Citrus* is undoubtedly of tropical origin. Alphonse de Candolle, after much investigation of historical and philological data, concludes that the feral range of the sweet orange is South China, Cochin China, Java, and Sumatra, with a possible extension into India, which regions are classed ecologically as tropical rain forest. Morphological evidence of the tropical origin of the orange is abundant, its tropical mesophytic nature being indicated by glossy, broad, flat leaves of rather loose and open cell structure, long life of leaves, absence of stomatal devices for regulating transpiration, lack of root hairs, and lack of a regular and non-interruptable period of dormancy. Livingston[1] has recently pointed out that the most efficient climate for plant growth in the United States is peninsular or tropical Florida. The significance of this is apparent when we remember that tropical Florida is the only place in the United States where the orange has run wild and been able so to maintain itself. In all countries where the sweet orange has run wild after having been introduced into the New World, such as Brazil, Paraguay, northern Argentina, and to some extent in Florida, the climate is distinctly tropical.

Horticulturists have called attention to the fact that an environmental complex which is most efficient as regards plant growth does not necessarily conduce to the production of fruit of high commercial value. On the other hand, some climatic factors, such as light and heat,

[1] Physiol. Res., vol. 1, April, 1916.

which in excessive amounts tend to retard vegetative growth, intensify
certain characteristics of the fruit which greatly enhance its market
value. Thus we find that the Bahia or Washington Navel variety of
Citrus sinensis has comparatively little commercial value at Bahia,
Brazil, where it originated, or in any other tropical country where it
has been tested. In a semitropical desert environment, however, this
variety of orange is high in sugar content, has skin characteristics
which lessen decay in transit, and is possessed of a deep reddish orange
color which increases its salability. For these reasons the cultivation
of oranges under arid and semiarid conditions has developed into an
industry of large importance, in which many millions of dollars are
invested and upon which many thousands of people are dependent for
a livelihood.

When we consider the morphological characteristics of the more or
less xerophytic vegetation indigenous to the region now occupied by
orange orchards in California and note the striking dissimilarity
between the forms of native plants and citrus trees, we may reasonably
suspect that our orange trees may find it more or less difficult to adjust
themselves to the new and strange environment. Perhaps the under-
ground environment provided by soils which, on account of low rainfall
and consequent lack of leaching, still retain a large proportion of the
soluble salts resulting from the decomposition of soil minerals, would
be equally as disordered as the above-ground environment were it not
for the fact that water artificially applied by irrigation lessens the
asperity of the conditions met by the roots. Not only is the total
environmental complex to which our orange trees are exposed incon-
sistent with their natural requirements, but the trees of the Washing-
ton Navel variety are themselves decidedly abnormal. It is the
universal practice to place scions of the desired variety upon rootstocks
of other species of *Citrus* so that the reciprocal influences between
stock and scion come into full play. Moreover, the variety in question
bears some indications of hybrid origin. The blossoms are entirely
devoid of viable pollen, functional ovules are few, the fruits are
partially double, peculiar in structure and seedless, and the vegetative
parts exhibit an erratic polymorphism which has so far proved
decidedly puzzling.

It is a matter of common observation that in the interior desert-like
valleys of the arid southwest the Navel orange is somewhat dwarfed
in stature, the leaves tend to persist to an unusual age, the volume of
bloom is abnormally large, shedding of the flowers and young fruits is

excessive, and various physiological derangements of nutrition are of frequent occurrence.

In many interior localities where there are but few pests to hinder the growth of the tree and where the climatic conditions favor the production of early maturing fruit of good color and high sugar content, the excessive shedding of young fruits, or "June drop," as it is called, is particularly exasperating to growers, who would undoubtedly make much greater profits if some way could be devised to prevent that part of the drop which is in excess of the normal and necessary amount.   An investigation of this problem was undertaken by the writers in response to a resolution passed by the California State Fruit Growers' Convention calling the attention of the university authorities to the urgent need of an investigation of this subject.   The results secured from observations and experiments during the summers of 1916 and 1917 are brought together in his paper.

Most of the field experiments from which our data have been obtained were carried on at two stations in Kern County; one at Edison in the orchards of the Edison Land and Water Company, about eight miles southeast of Bakersfield, and the other about two miles and a half distant at East Bakersfield in the orchard of Dr. C. W. Kellogg.   Both stations, on account of being situated to leeward of a considerable stretch of desert typical of the southern San Joaquin Valley, experience the extreme climatic conditions referred to above. The Navel orange matures early and is of excellent quality, and were it not for the light crops borne this district would be considered excellent for the production of Navel oranges.   Under these climatic conditions, unmodified, the drop occurs every year and is not dependent on the occurrence of dry hot winds, as is the case in southern California.

At Edison the Navel orange trees appear healthy and vigorous, the leaves and branches being quite free from fungous parasites and scale insects.   Except for an occasional slight showing of mottled-leaf disease the trees may be considered very thrifty and of good size for their age, which is eight years. A general view in this orchard is shown in plate 25.

The soil conditions are good.   The type is Delano sandy loam of good depth.   No general layer of hardpan exists.   Although certain bodies of hard conglomerate occur occasionally these are not in layer formation and do not interfere with the drainage.   The soil is rich in most plant foods, though low in nitrogn, which, according to an analysis kindly made by Dr. C. B. Lipman, runs from .025 per cent in

the first six inches to .012 per cent at a depth of three feet.   He also reports the nitrifying power of the soil as fairly good and the ammonifying power as high.   The organic matter content is quite low, much lower, in fact, than one would suppose from the healthy appearance of the trees.

Irrigation water is pumped from wells situated on the tract and the irrigation practice follows closely that of southern California.   Water is applied in four shallow furrows to each middle about once a month. This is followed in a few days by shallow cultivation in both directions.   The amount of water applied is sufficient to wet the soil five feet deep and throughout the whole area except for a small space between the trees in each tree row.   In June the temperature of the water as used is about 75° F.   Hilgard advanced the idea that June drop might be caused by low temperature of the irrigation water. While it is entirely possible that cold water may influence drop, we have found the drop to occur regularly where the water was not cold.

TABLE 1

MOISTURE DETERMINATIONS IN EDISON SOIL
Furrows run north and south

Location of sample with reference to tree	Depth	Per cent moisture based on water free soil	
		Before irrigating	After irrigating
North side	6 in.	5.70	6.38
North side	20 in.	5.04	6.95
East side	6 in.	6 72	12.61
East side	20 in.	7.99	10.25
South side	6 in.	5.70	6 04
South side	20 in.	7.87	7.29
West side	6 in.	7.52	11.48
West side	20 in.	7.06	11 60

A practical horticulturist after examining the trees and digging into the soil would hardly conclude that the trees were suffering for water. Moreover, Fortier states[2] that in sandy loam soils 6 per cent by weight of free water is sufficient to keep citrus trees in a vigorous condition. In the Riverside-Redlands districts the average moisture content of the soils in citrus orchards runs from 4 to 9 per cent, depending on the soil type.   In spite of this it is possible, of course, that the average moisture content of the Edison soil is below the optimum.

The management of the orchard consists of clean shallow cultivation throughout the year with a fairly deep plowing in March.   No cover crops have as yet been grown.   Light applications of manure and com-

[2] Irrigation of Orchards, U. S. Dept. Agr. Farmers' Bull. no. 404 (1910) p. 24.

mercial fertilizers are given. The roots of the trees fully occupy all of the middle spaces, and appear exceptionally healthy and vigorous. A large number of healthy roots were taken from a hole dug at the center of a square formed by four trees. The vertical distribution of roots is good. A hole two feet square was dug to the southwest of a tree well beyond the spread of the branches. Each six-inch soil layer was kept separate and the roots sifted out. On account of the dryness of the air comparative weights were not made, but the root distribution between the second and sixth six-inch layer is well shown in plate 42.

The general health and appearance of the trees at the Kellogg orchard is in every way similar to that at Edison. The orchard is one year younger than the plot used in the experimental work at Edison, but there is no appreciable difference in the size of the trees, unless it be in favor of the trees at the Kellogg place, which is to be explained as due to the method of handling the orchard.

Soil conditions are fairly similar, except that the surface soil at Edison is considerably heavier and more compact than at East Bakersfield, where the soil would be classified as a medium sand. However, it becomes heavier as one goes down until, at a depth of two feet, there is no noticeable difference in the soil at the two stations. We are not able to present analyses of this soil as to plant food, but there is no reason to believe that it differs markedly from that at Edison.

A radical difference, however, is manifest in the management of the two orchards. The main part of the Kellogg orchard is planted to alfalfa (pl. 26), and the portions in which our experimental work was done have had alfalfa grown between the trees for three or four years. Before planting the alfalfa the orchard was carefully and effectively laid out in small checks draining one into the other. The trees are protected from having water standing about their trunks by ridges thrown up just under the drip of the trees. These checks as well as the ridges are occupied by a good stand of alfalfa, which is cut for hay and hauled off. Irrigation water is pumped from wells and is applied in copious amounts, the period between irrigations averaging about three weeks, or a week to ten days shorter than that at Edison. There can hardly be any doubt but that considerably more water is applied to these trees than at Edison. Applications of commercial fertilizers have been made to the orchard from time to time. No detailed study of the root distribution was made but a few holes dug for other purposes seemed to indicate that the roots tend to go down or away from the surface in this orchard rather than to be localized in the upper soil layers.

Another distinctive feature of the Kellogg orchard is that it is protected on three sides by a fairly efficient windbreak. On the north, from which direction the prevailing winds blow, this consists of a double row of pepper trees (*Schinus molle*), and a single row of poplars. On the other two protected sides, the east and the west, there are rows of eucalyptus.

The Nature of June Drop

A cursory investigation of the problem at once established the fact that the young oranges are shed while still alive and actively functioning and as such the shedding constitutes true abscission. It is of course quite a different process from exfoliation, which involves the formation and activity of a phellogen. Before proceeding to a discussion of the process of abscission as determined by us, it may be well to discuss the amount of bloom, time of abscission, reaction time, and other important features.

Navel orange trees growing under the conditions studied always bloom very heavily (pls. 27, 28, and 29). The blossoms are borne on shoots of the current season's growth, being preceded and accompanied by new leaves. The old leaves do not fall until anthesis is well under way or completed. It is evident, therefore, that during anthesis the trees are under a heavy drain, inasmuch as they are called upon to support a heavy bloom in addition to both the new and old crops of leaves. Shedding of the unopened flower buds occurs to a small extent only. The opened flowers exhibit a certain amount of dimorphism. Those capable of setting fruit possess large, fully formed ovaries, with plump styles and stigmas. In many of the flowers, however, the pistils show a varying degree of degeneration and shedding of the flowers is largely confined to such individuals, beginning with the least robust and grading off during petal fall and including many of the most robust after petal fall. The period of maximum shedding takes place when the young fruits are from one-half to two centimeters in diameter. At first the point of abscission is always at the base of the pedicel (pl. 30), but after the diameter of the fruit has reached one centimeter or thereabouts it is usually at the base of the ovary. It is interesting to note that where the larger fruits absciss at the base of the ovary, abscission usually occurs also in the cortex at the base of the pedicel; but on account of the formation of strengthening tissue the process is not completed through the vascular elements and although the pedicel dies, it remains very firmly attached to the twig. This is shown in plate 31. It often happens that a certain amount of strength-

ening tissue at the base of the ovary may prevent the fall of the fruit. These dead, dry fruits, as shown in plate 31, are often quite conspicuous on the trees. Soon after the application of the stimulus, but several days before actual separation, the larger fruits assume a characteristic appearance, losing their luster and taking on a lighter green color. In the case of exposed fruits the yellow color is deeper around the apex, but this is not the case with shaded fruits. It is thus a simple matter to select any number of fruits which are destined to absciss several days before separation actually occurs.

Experiments carried on in the laboratory and observations made in the field, both in a survey of the citrus districts of southern California immediately following the heat wave of June 15–17, 1917, and at Bakersfield during 1916 and 1917, have shown that the time intervening between the application of the stimulus and actual separation is from four to ten days. The shorter periods were obtained in the laboratory, where the room temperature was uniformly high. Our observations are that under field conditions abscission is ordinarily complete within five to eight days after the application of the stimulus.

Normally, orange blossoms, being borne in cymes, open in succession, beginning about March 20 in the San Joaquin Valley and continuing about one month. Abscission varies with the season but usually it is in evidence from April 1 to about July 1, a period of three months. The period of maximum shedding occurs during the latter half of April. It should be noted that the season of 1917 was unique in being the latest on record. Protracted cool weather delayed the bloom fully five weeks, with a consequent delay of the period of maximum shedding. A comparison of the mean maximum atmospheric temperatures for the years 1914–17 inclusive is shown in table 2. The comparative lateness of the 1917 season is apparent from a study of this table.

TABLE 2

MONTHLY MEAN MAXIMUM TEMPERATURES FOR TEN MONTHS AT BAKERSFIELD

Compiled from U. S. Weather Bureau Records

	1914	1915	1916	1917
January	61.2	60.3	57.8	59.3
February	67.9	65.2	69.9	68.2
March	75.8	71.8	73.8	69.5
April	78.5	75.3	81.6	74.7
May	86.6	77.5	81.1	77.4
June	94.7	92.8	93.0	95.6
July	100.2	98.8	99.0	104.4
August	101.9	101.5	95.2	100.5
September	88.0	91.9	93.2	94.3
October	82.9	87.8	76.1	88.5

Turning now to a more detailed account of the abscission process itself we find that this subject has received considerable study and investigation. The nature of the abscission process has been studied and described in detail by Hannig[3] and Lloyd[4] for *Mirabilis;* Balls[5] and Lloyd[6] for *Gossypium;* Loewi[7] for *Ampelopsis;* Kubart[8] for *Syringa* and *Nicotiana;* Kendall[9] for *Nicotiana;* Tison[10] and Lee[11] for many other plants, to mention only a few of the researches in this interesting field. While the histology of abscission in *Citrus* has been described in detail elsewhere[12] by the junior author, it is appropriate that a brief sketch be included here.

As previously indicated, there are two entirely distinct abscission zones. One is at the base of the pedicel and the other at the base of the ovary. In each case the zone may be considered to be situated at the base of an internode where, on account of the power of forming adventitious buds, it may reasonably be suspected that the tissue retains, to a degree at least, its meristematic nature. The zones consist of ten to eighteen layers of cells which in young tissue differ histologically very little, if any, from adjacent tissues In older material differences involving shape, size, and content appear That in the case of young tissue differences of some kind do exist is shown by the fact that after the stimulus has been applied, yet ten to fifteen hours before visible indications appear, the walls of abscission cells are differentiated by a marked inability to hold certain stains, such as methylen blue. From six to eight hours before abscission the walls of the abscission cells are refractive to a different degree.

The first indication of actual abscission is a marked swelling and and gelatinization of the walls, which may amount to as much as 200

    [3] Untersuchungen uber das Abstossen von Bluten, Zeitschr. f. Bot., vol. 5 (1913), p. 417.

    [4] Abscission in *Mirabilis Jalapa,* Bot. Gaz., vol 61 (1916), pp. 213-30, pl. 13.

    [5] The Cotton Plant in Egypt (London, Macmillan, 1912), p. 69.

    [6] The Abscission of Flower buds and Fruits in Gossypium, and its Relation to Environmental Changes, Trans. Roy. Soc. Canada, ser. 3, vol. 10 (1916), pp. 55–61.

    [7] Blattablosung und verwandte Erscheinungen, Vienna Acad. Proc, vol. 1 (1907), pp 166–983; S B. d. math. nat. Kl. d. k. Akad. Wiss., Wien, vol. 116, abt 1 (1907), pp. 983–1024.

    [8] Die organische Ablosung der Korollen nebst Bemerkungen uber die mohlsche Trennungsschicht, *Ibid.,* vol. 115 (1906), p. 1491.

    [9] Abscission of Flowers and Fruits in the Solonaceae with special reference to *Nicotiana,* Univ Calif. Publ. Bot., vol. 5 (1918), pp. 347–428.

    [10] Recherches sur la chute des feuilles chez les Dicotylédones, Mém. Soc. Linn. Normandie, vol. 20 (1900), p. 125.

    [11] The Morphology of Leaf Fall, Ann. Bot., vol. 25 (1911), pp. 51–106.

    [12] An Account of the Mode of Foliar Abscission in *Citrus,* Univ. Calif. Publ. Bot., vol. 6 (1918), pp 417-28.

to 300 per cent. This is followed by dissolution of the gelatinous walls, thus freeing the cells which are now surrounded merely by the very thin and delicate tertiary membrane. No elongation of the tertiary membrane has been observed. Neither has any cell division prior to separation been seen to occur, although immediately following separation this often takes place. So far as ascertained, therefore, abscission in the orange conforms to the usual type, e.g., schizolysis[13] representing dissolution of the middle lamellae of the abscission zone cells by hydrolysis with subsequent separation.

STIMULI LEADING TO ABSCISSION

The direct cause of abscission in plants in general is considered to be some stimulus which may be brought into play in a variety of ways, depending somewhat on the nature of the plant involved. Lloyd[14] has taken pains to enumerate some of the different kinds of stimuli which according to various writers have been found to cause abscission. It is our purpose to consider these in turn as a possible cause of abscission in the Navel orange and possibly by elimination to arrive at the true cause or causes involved.

MECHANICAL SHOCK OR TRAUMATIC STIMULI

Fitting[15] has shown that jarring or shaking the flower stalks of *Verbascum* sp. and *Geranium pyrenaicum* will result in abscission within a few minutes. We were unable to produce like results with *Citrus* by this method. Moreover, abscission has been observed to occur regularly under conditions which would preclude the possibility of this cause being operative with oranges.

An effort was made to cause abscission by cutting and bruising the young fruits in various ways. The result was a failure in every case. Excision of the style and petals either separately or together, either before or during anthesis, failed to produce abscission Many of the fruits from which the style had been removed developed to maturity in a normal way. Others abscissed but the reaction time varied so widely as to make it very improbable that the removal of the style was the stimulus involved.

13 Correns, Vermehrung der Laubmoose, Jena, 1899. (Cited from Lloyd.)

14 Abscission, Ottawa Naturalist, vol. 28 (1914), pp. 41–52, 61–75.

15 Untersuchungen über die vorzeitige Entblätterung von Blüten, Jahrb., f. Wiss. Bot., vol. 49 (1911), p. 187.

In many plants insect injuries have been shown to be the cause of abscission. The case of the cotton boll weevil is perhaps the best known example, though it is likely that young fruits of the plum and apple react to injuries due to the curculio[16] and codling moth[17] in much the same way. In view of these observations it is interesting to find that oranges are a marked exception to the rule, the young fruits being particularly resistant to the effects of insect wounds.[18] In the San Joaquin Valley there are two insects at least which cause serious injury to the fruit. The work of *Scirtothrips citri* results in an extensive though superficial scarring of the fruit, yet the fruit develops to maturity. The nymphs of the fork-tailed katydid, *Scudderia furcata,* eat holes in the young fruits (see pl. 32), the holes sometimes extending entirely through the orange. This insect produces traumatic stimuli of the first magnitude, yet they do not result in abscission. Large numbers of the chewed, deeply scarred and distorted fruits develop to maturity only to be discarded by the pickers at harvest time.

Mechanical shock produced by transplanting trees or the root pruning incident to heavy spring plowing, such as is necessary to turn under a rank-growing cover crop, is usually followed by more or less dropping of the leaves and fruit. It is believed, however, that this may be accounted for by the disturbance of the water relations which follows root pruning rather than by the mechanical shock alone. Balls,[19] by root pruning cotton plants in Egypt, was able to cause abscission of the bolls, which he explained on the ground of water relations rather than shock. This particular phase of the problem will be again referred to later.

AIR TEMPERATURES AND LIGHT CHANGES

Abnormally high air temperatures or sudden changes in the temperature are by some investigators considered the cause of abscission in certain cases. It is evident that the question of the influence of air temperature is so involved with other important questions, such as the influence of humidity, air movement, transpiring power and the like, that it is inadvisable to assign specific influences to this factor alone. The same is true of changes in light intensity. Suffice it to say, how-

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[16] The Plum Curculio, U. S. Dept. Agr. Bur. Ent., Circ. 73 (1906), p. 4.

[17] The Codling Moth, *ibid.,* Yearbook (1887), p. 90.

[18] True in California, though Hubbard mentions the punctures of two insects, *Dysdercus suturellus* and *Leptoglossus phyllopus,* as causing the dropping of mature oranges in Florida. Hubbard, H. S., Insects Affecting the Orange, U. S. Dept. Agr., Div. Ent. (1885), pp. 167–69.

[19] *Loc. cit,* p. 68.

ever, that while a sudden rise in temperature may be and often is accompanied by increased shedding rates, it has been observed by the writers that profuse shedding of the young Navel oranges takes place during periods when no sudden changes or abnormally high temperatures occur. It has also been noted that abscission of the interior and well shaded fruits takes place simultaneously with that of fully exposed fruits. It is altogether unlikely, therefore, that the June drop can be explained on these grounds alone. The relation between abscission and tissue temperatures as affected by water deficits will be discussed in another place.

Many investigators have noted the marked effect of increase in air temperatures on the time involved in the separation process, and we have noted the same phenomenon. The effect of course, as would be expected, is an acceleration conditioned by the magnitude of the temperature change. It appears therefore to the writers that abscission following sudden increases in temperature, as noted by several investigators, may be easily explained on the ground that the stimulus to abscission had been activated at some time prior to the sudden change in temperature, and the acceleration of the abscission process, producing marked results in a comparatively short period, has led them to believe that the change in temperature is the causative stimulus.

Lack of Pollination and Fertilization

While there is a general rule that pollination and fertilization is essential to the setting and development of fruits, the rule is conspicuous for its exceptions. A number of our commercially important fruits, such as bananas, Sultanina grapes, Japanese persimmons, and Navel oranges, are distinctly parthenocarpic and do not require the stimulus of pollination to insure the setting of fruits which are usually seedless. The Navel orange does not produce viable pollen, and pollen from other varieties will only occasionally accomplish fertilization for the reason that nearly all of the embryo sacs disintegrate instead of developing into normal ovules capable of being fertilized.[20] Occasionally a few normal embryo sacs may be produced and seeds result provided the particular fruits having the normal embryo sacs happen to be pollinated with viable pollen from congenial varieties. It is the remoteness of the chance of this occurring under ordinary field conditions that accounts for the comparative seedlessness of these fruits. Apparently there is nothing in the structure of the blossom of the

20 Ikeda, T., On the Parthenocarpy of Citrus Fruits, Jour. Sci. Agr. Soc. Tokyo, vol. 63 (1904).

Navel orange which would interfere with the germination of pollen or the normal extension of the pollen tube.   The exclusion of pollen by the bagging method has shown that in setting fruit the Navel orange is entirely independent of pollen.   This experimental evidence is borne out by the practical experience of growers who secure as abundant crops from large isolated plantings of Navels as from mixed plantings. It is therefore entirely safe to conclude that lack of pollination and fertilization of the Navel orange does not result in the stimulus leading to abscission.

RELATIVE POSITION ON STEM

There is some variation in the relation borne by orange fruits to the main supporting axis.   As it has been suggested that with some other plants this relation largely determines whether a given fruit will be able to persist, it was thought worth while to investigate the importance of this point in connection with oranges.   A large number of fruits were examined and divided into two classes: those which terminated the axis, and those which did not.   These two classes are well illustrated in plate 33.   It seems reasonable to suppose that in the case of the non-terminals, an organ of limited secondary thickening (the pedicel) being in competition with one of unlimited secondary thickening (the main axis) might suffer from an increasing prejudice to its water supply.   It was found by counts of large numbers of fruits that the ratio of terminals to non-terminals was 5 to 6.   The new current season's growth which bore terminal fruits averaged 3.8 leaves per shoot, while the non-terminals averaged 3.95 leaves per shoot.   In the latter case 1.85 leaves were below and 2.1 leaves above the fruits.   Counts of fruits which had successfully survived the abscission period showed on one tree 16 terminals to 31 non-terminals, but on another tree 25 terminals to 14 non-terminals.   Counts of dropped fruits also failed to support the above supposition, and it is evident from our examination of large numbers of specimens that abscission in this case is quite independent of such differences in the relation of fruit to axis as is shown in plate 33.

THE GAS FACTOR

It has long been recognized that the subjection of certain plants to an atmosphere containing traces of various narcotic or poisonous gases is sufficient to cause abscission of leaves and other plant parts.   One of the first indications of smelter fume injury is the shedding of the leaves of certain plants due to the presence of sulfur dioxide, which is

a combustion product in the reduction of sulfur-containing ores. G. J. Pierce[21] has shown that when SO_2 is present in as small quantities as three to five parts per million abscission of the leaves of certain forest plants occurs. Several investigators have reported abscission of flowers and leaves of various plants when subjected to minute traces of illuminating gas, ether, chloroform, ethylene, and other poisonous gases. Further, two investigators have reported[22, 23] abscission of the leaves of citrus plants when subjected to an atmosphere containing traces of illuminating gas. We have obtained similar results with potted plants. Within four days after subjection to illuminating gas all the leaves were shed.

The exhaustive work of L. I. Knight and W. Crocker[24, 25] on the effects of illuminating gas and smoke upon plants has shown rather conclusively that the response is largely if not entirely due to the toxicity of the ethylene present. It has been shown by E. M. Harvey[26] that as minute traces as one part per million are sufficient to cause marked reactions on the part of the plant.

Preliminary experiments carried out in our laboratories with excised citrus shoots subjected to various gases, including illuminating gas, have indicated that under such conditions abscission is not appreciably accelerated by any of the gases. The time at which shedding of the leaves took place was approximately the same in ordinary room atmosphere as in varying concentrations of illuminating gas.

Peirce[27] has shown that one of the effects of smelter fumes is to cause excessive transpiration from certain plant parts prior to their abscission. This is accounted for by the decomposition of the chlorophyll in the guard cells of the stomata, resulting in decreased stomatal regulation of transpiration. As will be pointed out later, several investigators have concluded that abnormal water loss during a part of the day, resulting in considerable fluctuations in the leaf

21 1. A Report of an Investigation conducted for U. S. Department of Justice, 1913, unpublished manuscripts in the hands of U. S. Attorney General. 2. Report of Selby Commission, to U. S. Bureau of Mines, 1913.

22 In *Citrus limonia*. Shonnard, F., The Effect of Illuminating Gas on Trees, Yonkers, N. Y., Dept. Pub. Works (1903), p. 48.

23 In *Citrus decumana*. Doubt, Sarah S., The Response of Plants to Illuminating Gas, Bot. Gaz., vol. 63 (1917), pp. 207–24.

24 The Effect of Illuminating Gas and Ethylene upon Flowering Carnations, Bot. Gaz., vol. 46 (1908), pp. 259–76.

25 Toxicity of Smoke, *ibid.*, vol. 55 (1913), pp. 337–69.

26 Some Effects of Ethylene on Metabolism of Plants, *ibid.*, vol. 60 (1915), pp. 193–214.

27 Expert testimony incorporated in Records of Federal Court, District of Utah, Salt Lake City.

water content, is sufficient in certain plants to cause abscission. In the light of these observations abscission of plant parts when exposed to smelter fumes is explainable purely on the basis of abnormal water relations.

In an effort to ascertain whether in the case of illuminating gas any such relation holds true, we have made a careful study of the stomata of citrus leaves and have to report that at an early period in the life of the leaf they lose their power of functioning and remain practically closed thereafter. This is significant in view of our findings mentioned above, namely, that illuminating gas is not a direct stimulus to abscission in *Citrus*, at least with excised shoots. In the case of potted plants it seems probable that it works in an indirect manner through disturbances in the physiological balance. In connection with the question of the effect of illuminating gas upon the chlorophyll of the guard cells, it should be mentioned that H. M. Richards and D. T. MacDougal[28] have reported that chlorophyll formation is greatly retarded when the plant is subjected to an atmosphere containing traces of this gas.

The fumigation of citrus trees with hydrocyanic acid gas for the control of scale insects is practiced quite generally and with marked success in California. It is the general experience that under certain conditions heavy dosages of this gas result in abscission of the older leaves.[29] Researches by Osterhout[30] and Moore and Willaman[31] have shown that when subjected to traces of this gas the permeability of cytoplasmic septa is markedly altered, causing an increased loss of water. In the light of these observations it is entirely possible to explain dropping of citrus leaves due to fumigation on a purely water relation basis.

Fumigation injury to the blossoms or fruit, whether large or very small, consists of pitting and burning which results in scars on the fruit. Apparently in no case does fumigation of young Navel oranges with hydrocyanic acid gas furnish a stimulus to abscission.

The whole subject of the effect of gases in causing abscission of plant parts is in a very unsatisfactory state at the present time. In view of the mass of conflicting data, as well as the fact that abscission

[28] The Influence of Carbon Monoxide and other Gases upon Plants, Bull. Torr. Bot. Club, vol. 31 (1904), pp. 57–66.

[29] Woodworth, C. W., and others, School of Fumigation, Pomona, California, pp. 162–64, August, 1915.

[30] Similarity in the Effects of Potassium Cyanide and of Ether, Bot. Gaz., vol. 63 (1917), pp. 77–80.

[31] Studies in Greenhouse Fumigation with Hydrocyanic Acid: Physiological Effects on the Plant, Jour. Agr. Res., vol. 11 (1917), pp. 319–38.

of young Navel oranges occurs throughout the great interior valleys of California and in districts very remote from any possible source of noxious vapors, there is little possibility that the gas factor can be operative in the case under consideration.

Fungi and Bacteria as a Cause of Abscission

Although the belief is commonly held by plant pathologists that fungus parasites sometimes cause the shedding of plant parts, the literature on this phase of abscission is very meager. Inoculations with *Bacterium citrarefaciens*, the organism causing Citrus Blast. carried on in our greenhouses have shown that when the organism is inoculated into the tip of the young leaf the latter is shed within a few days. Rolfs has reported that shedding of mature oranges frequently occurs in Florida, due to the common wither tip fungus, *Colletotrichum gloesporioides*. However, we are concerned here with the shedding of immature fruits and it is by no means clear that the process resulting in shedding is the same in both cases.

For many years growers of Washington Navel oranges have experienced losses from a black rot disease of the fruit which manifests itself as a stimulation of the fruit, causing it to grow to an extra large size, ripen early and assume a deep red color, with a certain amount of dropping. This disease was first noted by N. B. Pierce[32] in 1892 and was first described by him in 1902[33] as "Black Rot of the Navel Orange" caused by the fungus *Alternaria citri*.

The fruit is infected when quite small, probably just before or soon after the style is shed, through the cracks and imperfections in the proliferations of the navel (pl 34) The fungus is a weak parasite and remains quiescent, or nearly so, during the growing period of the young fruit, at which time the fruit is more or less resistant to the encroachments of parasites. With the decline in vigor incident to approaching maturity the fungus becomes more active and exerts a stimulating influence on the fruit, causing it to take on a deep reddish-yellow color and to ripen earlier than the normal fruit. In a small and restricted area the cells of the pulp are broken down and become a nauseating mass of black fungus mycelia and spores. The rind is left uninjured until the disease has made considerable progress within, but ultimately a black and decayed spot appears on the surface near the navel end. A certain proportion of the infected fruits early shows a yellow spot

[32] U. S. Dept. Agr. Yearbook (1892), p. 239.
[33] Bot. Gaz., vol. 33 (1902), pp. 234–35.

about the navel end and drops from the tree when about one to two inches in diameter, or even larger. The remainder persist to maturity, the disease coming into evidence at picking time, in transit, in storage, or not until in the hands of the consumer.

Early in 1916 our attention was directed to the fact that on dissection a relatively large number of the shed fruits and fruits about to drop were found to have a discolored area under the navel end. In many cases a dark colored, gummy mass was present, although in others the tissue immediately under the navel was only slightly discolored (pl. 35). In some fruits there was no evidence of any such spot or area. A few of the dropped fruits were sterilized in mercuric chloride (1–1000) and placed in small moist chambers. To our surprise these cultures showed practically 100 per cent infection with an *Alternaria*. Other cultures were made with the same results. Therefore we concluded that it was well within the realm of possibility that the June drop was due to the same fungus causing black rot and decided to investigate the matter more thoroughly.

The fruits had reached a size of one or two centimeters and the blooming period was entirely over, precluding any investigation as to the source and manner of infection in 1916. Therefore our efforts in this direction during 1916 were confined to attempts to determine, if possible, the extent of the infection. Cultures of many hundreds of shed fruits, and fruits about to fall, from many districts of the state were made both by the method above described and by inserting a piece of tissue from the discolored area into slanted tubes of Shear's corn meal agar. The cultures uniformly showed a high percentage of infection with *Alternaria*. A few cultures were then made using healthy green fruits picked from the trees. The percentage of infection was small. Still later in the season dropped fruits from four to five centimeters in diameter (pl. 35) were collected from districts as far apart as Oroville in the Sacramento Valley and El Cajon near San Diego. Cultures made from these fruits showed practically 100 per cent infection.

Although the number of cultures made was too small to justify a broad generalization, the work done in 1916 was sufficiently productive to form the basis for a working hypothesis which was advanced as a theory to account for the June drop of Washington Navel oranges. Other experimental work under way had indicated the presence of certain abnormal water relations between the young fruits and the leaves immediately behind them, which phenomenon

will be discussed more fully in a later section.   Briefly, the theory advanced was that excessive transpiration from the leaves caused water together with enzymatic solutions secreted by the fungus in the navel end to be drawn back through the vascular system of the young fruits through the pedicel and thus provide the stimulus to abscission.[34]

That there is no mechanical difficulty involved in this theory was borne out when by means of dyestuff solutions it was demonstrated that the vascular system running to the navel or secondary orange traverses the central pith or core of the primary fruit, which thus serves as receptacle and stem to the smaller fruit (fig. 1).
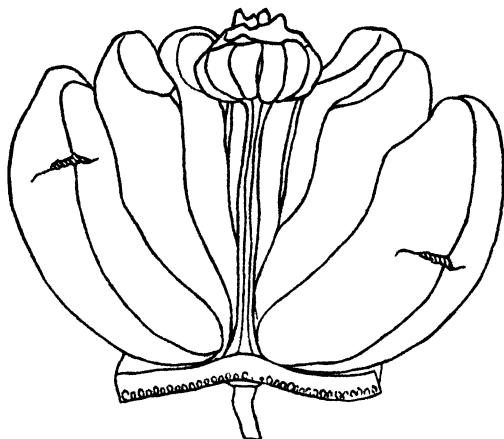
Fig. 1. Structure of the Navel orange. The central pith containing fibro-vascular bundles acts as the stem of secondary fruit.

Further evidence tending to support this theory lies in the fact that black rot is much more prevalent in the interior valleys than in the coast regions.   In fact, there seems to be a certain correlation between the amount of black rot and the amount of drop.   The reason for the greater prevalence of black rot in the hotter, more arid districts was not uncovered until later; this will be brought out in another section.

Alternaria citri, Ellis and Pierce

During the winter of 1916 a careful study of the alternarias obtained in our cultures was made and disclosed the fact that although there were several strains of *Alternaria* obtained, one particular type rather easily recognizable after a little practice, was by far the most

[34] Coit, J. Eliot, and Hodgson, R. W., The Cause of June Drop of Washington Navel Oranges, Univ. Calif. Jour. Agr., vol. 4 (1916), p. 10.

common. In addition we obtained one strain possessing the ascigerous stage, which of course classified it in the genus *Pleospora*. Several *Macrosporium* strains were also isolated.

Considerable effort was made to identify the *Alternaria* strain so commonly found, but we have been unable to satisfy ourselves thoroughly in this regard. While the literature is indeed voluminous, there is apparently no reliable monograph of the genus. Recently, however, there has appeared a critical study of the taxonomic characters of the genus.[35] The genus *Alternaria* is one of the most universally distributed of the common forms of the *Fungi Imperfecti*. It embraces about fifty species, although it has been shown by Elliott that a large number of the species of the closely related genus *Macrosporium* really belongs to the genus *Alternaria*. Among these species we find active parasites as *A. solani* (E. and M.) J. and G., weak or facultative parasites as *A. citri* Ellis and Pierce, and saprophytes as *A. tenuis* Nees. Certain species have already been secured in the perfect or ascigerous stage which has always proved to be *Pleospora*. Since the strain under consideration was uniformly obtained from oranges in a district where black rot is common it is probably the same form found by Pierce and called *Alternaria citri*. We were unable to find the original description by him, which does not seem to have been published. However, after examining the literature and drawings of *Alternaria citri*, particularly as given by Rudolph,[36] we feel reasonably sure that we are dealing with *Alternaria citri* E. and P. and throughout the remainder of the discussion we shall proceed on that assumption.

The spores of *Alternaria citri* are borne in long chains (pl. 36), which readily break up, allowing the spores to float away in the air. It seemed important to determine whether the infection of oranges was accomplished by spores borne by the air or those carried by honeybees and other insects. The following methods were employed. Petri dishes containing Shear's corn meal agar were exposed for five minutes in different localities. After a few days had elapsed in order to allow the various bacteria, molds and other fungi to assume colony form and the *Alternaria*, if present, to produce spores, the dishes being inverted were placed under the low power of the microscope and the colonies of *Alternaria* easily distinguished and counted. On account of the length of the spore chains and certain other morphological

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[35] Elliott, J. A., Taxonomic Characters of the Genera *Alternaria* and *Macrosporum*, Am. Jour. Bot., vol. 4 (1917), pp. 439-76

[36] A New Leaf Spot Disease of Cherries, Phytopathology, vol. 7 (1917), pp. 188-97.

characters which became familiar with practice, it was easy to distinguish between various other species of *Alternaria* which were occasionally met with.

The specialized cells lining the stylar canal of orange flowers secrete a pure white sugary mucilage which is exuded upon the stigma in a rather large drop. This material is an excellent medium for the growth and sporulation of *Alternaria,* as was determined by trial, the fungus fruiting heavily in a short time on smears kept in a moist chamber. In order to determine the amount of infection of blossoms in the orchard, the stigmas were clipped with sterile scissors on agar plates and the resulting growths examined a few days later for the characteristic spore chains. The data secured in this way are presented in tables 3 and 4. In the interior valleys 89 per cent of the stigmas were infected and in coast localities 76 per cent. It is found that the air generally throughout the state carries *Alternaria* spores in abundance. In interior localities *Alternaria* spores were taken in 78 per cent of exposures with ten centimeter agar plates; in some places near the coast in 63 per cent. It was also shown that while bees may and do carry spores from one blossom to another the number of spores in the air is sufficient to cause widespread infection without the aid of bees.

TABLE 3

NUTRIENT AGAR PLATES EXPOSED TO THE AIR, 1917

Locality	Date	*Alternaria* present	*Alternaria* not present
Whittier	May 3	18	3
Highland	May 6	10	0
Edison (under tent)	May 3	1	2
Oroville	May 14	10	2
Berkeley	May 17	0	4
Fresno	May 28	2	0
San Leandro	June 3	1	4
Fair Oaks	June 12	5	0
Edison (orchard)	June 22	1	2
Edison (desert)	June 22	3	2
Corona	June 27	3	0
Whittier	June 26	2	1
Riverside	June 29	6	3
Berkeley	Oct. 25	1	5

In this connection the question naturally arises as to why, if the infection of the stigmas near the coast is as great as 76 per cent, there is such a relatively small number of black rot oranges. The reason apparently lies in the fact that the average configuration of the navels

is more irregular, jagged and rough (pls. 34 and 37) in the interior valleys than in the coast districts, where the navel formation is much more commonly smooth or submerged and closed. This imperfect and open condition of the navels in the interior valleys, as will be brought out later, is due to the harsher environmental complex to which the fruits are subjected during the growing period. Everyone is familiar with the fact that fruits borne in exposed positions, particularly in the top of the tree, are very apt to be coarse and rough with large protruding navels, while the interior fruit is much finer in texture. The prevalence of *Alternaria* spores in the coast districts is certainly not much less than in the interior valleys, but the amount of infection is much less because of the smaller number of imperfect navels.

TABLE 4

MISCELLANEOUS CULTURES

Locality	Date	Kind of material	*Alternaria* present	*Alternaria* not present
Whittier	May 3	Navel blossoms	10	0
Whittier	May 3	Valencia blossoms	2	2
Highland	May 6	Navel blossoms	14	0
San José	May 25	Blossoms	4	1
Oroville	May 14	Olive blossoms	1	0
Oroville	May 14	Navel styles	8	0
Oroville	May 14	Bees about trees	3	1
Oroville	May 14	Lady bird (*Vedalia* sp.)	1	0
Berkeley	May 17	Dead style from greenhouse	0	1
Berkeley	May 17	Dead twig from greenhouse	0	1
Fresno	May 28	Orange blossoms	5	0
Sacramento	May 25	Orange blossoms	5	0
Fair Oaks	June 12	Orange blossoms	9	0
Edison	Apr. 24	Orange blossoms	11	1
Edison	Apr. 25	Bees about trees	3	3
Riverside	June 27	Citron styles	2	0
Edison	May 2	Navel blossoms	4	1
Edison	May 2	Valencia blossoms	4	0
Edison	May 2	Pomelo blossoms	2	0
Edison	May 2	Soil from under trees	0	2
Edison	May 2	Bees about trees	1	1
Edison	May 2	Navel blossoms from tented tree	6	0

As is shown in table 4, *Alternaria* spores are present on almost all the styles, both in coast and in interior valley districts. In order to ascertain whether infection occurred by the fungus growing down through the style into the navel end, material known to be infected with *Alternaria* was put up in paraffine, sectioned, and stained. Although the fungus was conspicuous on the stigmatic surface no traces of fungus mycelium could be found in the stylar tissues. This fact, together with the fact that infection is definitely correlated with the

configuration of the navel end, renders it reasonably certain that infection occurs some time after the style has been shed. The spores are probably blown and find lodgment in ragged open navels where they are held in the crevices till enfolded and overgrown by the rapidly developing ovary (pls. 34, 37). Inasmuch as the configuration of the navel as well as its size and degree of insertion are exceedingly variable, it is evident that only in a comparatively small and variable number of cases are the spores or mycelium so situated as to permit germination or growth. *Alternaria citri* is a weak parasite and cannot penetrate the unbroken skin of an orange. While it is not capable of producing any widespread breakdown in the tissues of immature oranges, it is able, after introduction into the fruit, to bring about a certain stimulus or irritation which, according to our theory, results in abscission of a certain proportion of the young fruits. It is certain that as the fruits grow and approach maturity the abnormal size, premature ripening, and extra deep color are the direct results of this stimulation. It is also considered highly probable that a certain proportion of the splitting or dehiscence of the carpels which is so serious in interior valleys is connected with the stimulation of these infections.

Referring again to the wide distribution and general prevalence of *Alternaria* spores in the air, it is evident that the spores may be transported in large numbers for great distances. The source of infection is by no means limited to the vicinity of orchards. The fungus grows readily as a saphrophyte on dead leaves, weeds, twigs, and other plant débris and it is entirely possible for spores to be brought in from forest areas in the mountains many miles away. Spores have been taken in the desert far from cultivated crops. In the dry air of the San Joaquin Valley the black rot oranges which fall under the trees are not immediately decomposed by *Penicillia, Fusaria*, and other fungi. They tend to mummify and after the *Alternaria* spreads through the interior it comes to the surface, and the spores there formed give these mummies a black color, as shown in plate 38. These mummies, together with the large number of abscissed styles from the blossoms, undoubtedly furnish a greatly increased supply of spores at the critical time in the development of the fruit.

A rot of apples occurring in Colorado[37] has been described as caused by an undetermined species of *Alternaria*. Judging from the drawings presented in plate 4 of Longyear's publication, the fungus is very similar to if not the same as that with which we are dealing. Moreover,

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[37] Longyear, B. O., A New Apple Rot, Colorado Agr. Exp. Sta. Bull. 105, 1905.

there is a marked similarity between the modes of infection. According to Longyear (p. 7) :

> The reason why certain varieties of the apple are particularly subject to the blackened seed cavity is found in a structural peculiarity of such varieties. Thus a longitudinal section through such an apple usually shows a very deep calyx tube, which, in many cases, extends to or meets the core, or even opens into it. In such cases the fungus has evidently reached the core through this passageway *by following the united styles and the inner wall of the calyx tube.* (Italics ours.)

Only certain varieties of apples, such as the Winesap, Ben Davis and a few others which have the structural peculiarities above mentioned, are found to be affected and in this connection Longyear's remarks on page 12 are of particular interest to us.

> Some of these varieties are among those which are reported as dropping their fruit badly in some seasons during June and July, but whether or not the fungus plays any part in this matter has not been determined.

The experimental work with *Alternaria* in 1917 for several reasons gave quite different results from those obtained during the previous season. As is shown in tables 3 and 4, cultures made from stigmas early in the season showed a high per cent of *Alternaria* infection. However, a very large series of cultures made somewhat later in the season, from the young fruits one-half to two centimeters in diameter, to our astonishment showed a very small per cent of infection. Culture after culture showed no *Alternaria* at all. Somewhat later, when the fruits were larger, cultures of the shed fruits showed a higher per cent of infection, while a few cultures made when the dropped fruits were four to five centimeters in diameter showed a high per cent of *Alternaria* infection.

Inasmuch as by far the greater part of the drop occurs while the fruits are one-half to two centimeters in diameter, at which time our cultures showed comparatively little *Alternaria* infection, it is evident that the shedding of this part of the crop can not be attributed to *Alternaria.* However, it is to be noted that, as was the case in 1916, toward the end of the period of shedding the dropped fruits showed a steady increase in the per cent of infection. Evidently, then, the shedding may be divided into two parts, the first including small fruits which *may or may not* be infected with *Alternaria,* the second including larger fruits which *are* infected with *Alternaria.*

Inasmuch as the climatic conditions in the San Joaquin Valley during the 1917 season were considerably more severe than in 1916

(fig. 6), and therefore the average configuration of the navels more ragged and open, to what can we attribute this difference in the amount of infection with *Alternaria?* We believe that this difference is easily explained by a study of the mean maximum temperatures for the two seasons. In table 2 these are shown for the years 1914–17 inclusive. For the 1917 season, taking the months of January and February, we see that they are about average for the last four years. March is four or five degrees below the average, April still more, and even May is below the average. June is several degrees above the average for the last four years and July shows an average mean maximum temperature of 104.4° F, considerably above the average. In other words, the early part of the season was cooler than usual and the bloom was delayed a month or more. Coincident with the end of the blooming period the weather changed radically and became very hot and dry and continued so for at least three months. Conditions were unfavorable for infection by *Alternaria;* its growth was inhibited although the spores were present. In fact, the amount of drop due to *Alternaria* in 1917 is practically negligible, and this is supported by the fact that there were very few black rot oranges at Edison at harvest time. On the other hand, the season of 1916 was noted as a relatively cool, pleasant summer and as such was favorable for infection by *Alternaria,* with the result that there were many black rot oranges.

In this connection the question arises, why are not other citrus varieties grown in these arid districts subject to infection by *Alternaria* with a consequent shedding and loss due to black rot? The answer apparently lies in two facts: that other varieties are not so susceptible to shedding, which will be discussed later, nor are they morphologically adapted to infection by the fungus. Plate 39 shows the apical end of a small Valencia orange highly magnified and it is evident that there is no favorable entrance for the fungus spores. Plate 34 shows a similar view of a Navel orange with very favorable conditions for the lodgment of fungus spores.

During the course of these investigations a great deal of time and effort was devoted to attempts to ascertain by inoculation methods whether the stimulus of *Alternaria citri* which manifested itself so clearly in the change of color of the fruit might not also be the cause of abscission of the young fruits. On account of several peculiar difficulties inherent in this particular problem we have so far been unable to secure conclusive results. The three most important of these difficulties may be mentioned briefly as follows:

1. Referring again to plate 29, it is apparent that the excessive number of buds occasions a severe struggle for survival, only a comparatively small number being able to acquire water and food sufficient for development. As it is impossible to determine in advance which if any of a group of similar buds is destined to remain, it is evident that if the sterile stigmas of all are inoculated just previous to opening many will eventually fall from other causes. Moreover, the considerable period of time involved and the frequent necessary opening and closing of the bags in an atmosphere shown to be filled with spores would introduce an element of serious error. Plate 40 shows one of a number of trees used futilely in efforts to get results in this way.

2. Orange flowers are dimorphic, as before mentioned, a certain number being destined to fall because the ovary is not capable of ● development. The configuration of the navel is to a certain extent fortuitous. In some cases the epidermal folds are so adjusted as to admit infection, in others not. It is obviously out of the question to examine each fruit frequently and with sufficient minuteness to determine whether during growth an opening sufficient for the entrance of the fungus was or was not available.

● 3. A species of aphis is very common on *Malva* and other weeds under the trees. For some reason not at present clear, the insect is unable to increase to any extent when feeding on the orange leaves in the open. However, it was found that whenever a twig was enclosed in a paper bag or a tree enclosed in a cheesecloth tent (pl. 40) the aphis multiplied at an astonishing rate. In about half the bags on the tree shown the twigs were defoliated and killed by the sudden development of a mass of aphis from young and minute individuals which were inadvertently included within the bags in spite of all precautions.

Summing up the relation between *Alternaria* and that part of the June drop with which it is always associated, we have to conclude that inasmuch as the presence of the fungus and its ability to provide a certain stimulus have been demonstrated, it is not unreasonable to suppose that abscission may be another manifestation of the same stimulus both in the case of Navel oranges and in the apple varieties referred to above. Satisfactory scientific evidence of this point, however, is lacking as yet.

The Relation of Abscission to the Environmental Complex

It has long been noted that there exists a marked correlation between climatic conditions and the prevalence and amount of the June drop. This correlation has been discussed somewhat by the junior author in another place[38] and has been reflected in the general attitude of growers who are prone to assign June drop to hot north winds, sudden changes in temperature, and other causes, most of which are climatic in nature.

In order to obtain more accurate information in this regard an investigation of the yield per tree in different citrus districts, where all other factors except the climatic complex were comparable, was carried out during the season of 1917. The results were striking and show most pronounced correlation between climatic conditions and yield when all other factors such as orchard management, etc., are fairly comparable. It was found that, assigning a yield of 100 per cent to the district averaging the highest crop, which district is characterized by considerable summer heat but moderate atmospheric humidity, the farther inland the district lies the smaller is the crop. This is precisely the order in which the asperity of the environmental complex is heightened, the atmospheric humidity decreasing and the average summer temperature increasing. Moreover, and more important, distance from the coast brings with it increasing liability to sudden changes in the weather which react most unfavorably on crops, particularly when in certain stages. The districts where these climatic conditions are most severe, namely, the Coachella Valley and the southern San Joaquin Valley, show a yield of approximately 25 per cent of that of the most climatically favored district. At intermediate stations the extent of the drop and consequently the size of the crop is easily correlated with weather conditions during the critical period. This was exemplified by the almost total loss of the Navel crop in the district between Corona and Redlands in 1917, when a dry north wind of unprecedented severity was accompanied by maximum daily temperatures as high as 118°–120° F from June 15 to 17.

This correlation between asperity of climatic conditions and amount of crop, or what amounts to the same thing, the prevalence of dropping, was very apparent in the orchard where our experimental work was done at Edison. The yield from the particular ten-acre tract used was

56 per cent less in 1917 than in 1916 though the trees were a year older and should have yielded more. The asperity of climatic conditions during the critical period in 1917 as integraded in the Livingston white porous cup atmometer (pl. 41) was approximately 40 per cent greater than during the same period in 1916. This fact is brought out in table 5, where the water loss from atmometers at different stations in the United States is shown. "Grove" station in 1916 is fairly comparable with "Cultivated" station in 1917, as is the case with the two "Desert" stations. Further evidence of this correlation is afforded by the mean maximum temperatures obtaining during the critical period in the development of the young fruit (table 2). During this period in 1917 (June and July) the mean maximum temperatures were 95°6 F and 104°4 F respectively, while those for the critical period in 1916 (May and June) were only 81°1 F and 93°0 F.

TABLE 5

COMPARATIVE LOSS FROM CYLINDRICAL WHITE POROUS CUP ATMOMETERS AT
DIFFERENT STATIONS IN THE UNITED STATES FOR THE MONTH OF JUNE

Station	Average daily loss for 24 hours in cc.
Miami, Fla.*	15.9
Urbana, Illinois*	16.1
"Alfalfa" Station, East Bakersfield, 1917	18.5
Whittier, Calif., 1912	22.8
Berkeley, Calif., 1917	23.1
West Raleigh, North Carolina*	28.0
Gainesville, Florida*	28.7
"Tree" Station, Edison, 1916	32.9
San Diego, Calif.*	33.0
Cameron, Louisiana*	33.4
"Tree" Station, East Bakersfield, 1917	35.8
Riverside, Calif., 1912	43.4
Dickinson, North Dakota*	45.0
"Grove" Station, Edison, 1916	48.1
"Yard" Station, Edison, 1916	55.1
"Desert" Station, Edison, 1916	69.1
Reno, Nevada*	69.5
"Cultivated" Station, East Bakersfield, 1917	71.7
Tucson, Arizona*	73.0
Dalhart, Texas*	80.7
"Desert" Station, East Bakersfield, 1917	94.0

* Livingston, B. E., A Study of the Relation between Summer Evaporation Intensity and Centers of Plant Distribution in the United States, Plant World, vol. 14 (1911), pp. 205-22

This correlation is again reflected in the comparative yields in general throughout the state in the seasons of 1916 and 1917. The latter season has been noted for its long continued, high temperatures

and low humidity, while the former was as equally marked by its relatively low temperatures and equableness. The crop in 1917 over the entire state is not estimated to be more than 40 to 50 per cent of that in 1916.

All the more recent fundamental work in plant physiology has indicated that for plants growing in the open the water relation is the limiting factor. It is at once obvious that under the conditions obtaining in the arid southwest it is the water relation which is most likely to be strained. This is particularly to be considered in connection with the previously mentioned fact that the genus *Citrus* is undoubtedly of tropical origin and therefore not well adapted by nature to withstand the tremendous water loss incident to the severe climatic complex obtaining under arid conditions.

Evidence that abnormal water relations due to the influence of the environmental complex may furnish the stimulus to abscission is not lacking. In regard to the cotton plant Balls[39] says: "It is certain that the main factor, if not the only one, is the water-content of the plant." Lloyd,[40] also working with cotton, concludes that "the water deficit is the cause of rise of temperature in the tissues, and this constitutes the stimulus which directly leads to abscission." Howard[41] has noted the fact that abnormal water conditions in the soil are immediately shown in the indigo plant, *Indigofera arrecta*, by leaf-fall or by the shedding of flowers without setting seed. His interpretation of these results will be referred to later. The junior author has already presented data to show that at Edison an abnormal water relation does exist in orange leaves and young fruits during the critical period.[42] He has shown that a daily water deficit of 25 to 30 per cent occurs in the young fruits, which deficit is made up at night. These deficits are at their maxima during the afternoon, at which period the atmospheric pull on the plant for water is at its maximum. A contributing factor to these water deficits lies in the fact that under stress of the tremendous atmospheric pull for water the leaves actually appropriate water from the young fruits. This strain on the plant is not localized but extends throughout the tree. Tensions developed by exterior foliage are transmitted quickly to interior fruits and even to distant roots as was shown by several experiments; for the sake of brevity only one will be described.

[39] *Loc. cit.*, p. 69.

[40] The Abscission of Flower-buds and Fruits in *Gossypium*, and its Relation to Environmental Changes, Trans. Roy. Soc. Canada, ser. 3, vol. 10 (1916), p. 61.

[41] Soil Aeration in Agriculture, Agr. Res. Inst. Pusa, Bull. 61, 1916.

[42] *Loc. cit.*

On May 4, 1916, a large number of apparently healthy terminal fruits about one-half inch in diameter were selected on six trees at Edison. Lot A was left as a check, lot B was treated by clipping off with scissors one-third of the leaves of the current season's growth behind the fruit. Lot C suffered excision of two-thirds of the leaf area, and lot D had all of the leaves removed, leaving the fruit terminating a bare stem about six inches long. Unfortunately, a few of the limbs in these trees were removed by tree pruners. On November 16 the remaining labels were located and a record made of the number of fruits which persisted to maturity.

TABLE 6

EFFECT OF REDUCTION OF ADJACENT LEAF AREA ON ABSCISSION

	Number labeled	Number labels found	Number of fruit set
A. Check, not treated	200 ·	165	29
B. One-third leaf area removed .	200	163	19
C. Two-thirds leaf area removed	200	176	37
D. All leaves removed	200	167	21

Thus we see that the reduction of adjacent leaf area had no effect on the drop and inasmuch as eosin solution was drawn through oranges *in situ* to the stem in lot D very nearly as quickly as in lot A, it is evident that the tensions referred to have to do with the tracheal system as a whole, as is to be expected, and do not tend to be localized in any particular part of the tree.

TABLE 7

PRESENCE OF LITHIUM NITRATE IN LEAVES BEHIND FRUITS INJECTED WITH DRY CRYSTALS AS SHOWN BY THE SPECTROSCOPE

Experiment began at 12 M.

Time	First leaf	Second leaf	Third leaf	Fourth leaf	Fifth leaf	Sixth leaf	Seventh leaf	Twelfth leaf
12:30 P.M. 30 minutes	Posi- tive	Posi- tive	Posi- tive	Nega- tive	Nega- tive	....	Nega- tive	....
1:00 P.M. 1 hour	Posi- tive	... .	....	. ...	Posi- tive	Nega- tive	....	. ...
2:00 P.M. 2 hours	Posi- tive	....	....	Posi- tive	. ...	. ...	. ...	Nega- tive
3:00 P.M. 3 hours	Posi- tive	. ...	....	Posi- tive	.. ...	... .	. ...	. ...
4:00 P.M. 4 hours	Posi- tive	....	. ...	....	Posi- tive	Posi- tive	....	....
12:00 M. 24 hours	Ver, slight trace	Very slight trace	Nega- tive	Trace (?)	. ...	.. ..	....	....
Check	Nega- tive	Nega- tive	....	. ...	... .	....	....	....

The withdrawal of water from the fruits by the leaves has been further substantiated by the use of dry crystals of lithium nitrate injected into the navel end of the young fruits and testing for lithium in the leaves proximal to the fruits at different periods following injection by means of the spectroscope. These results are summarized in table 7, where it can be seen that within a half hour, in spite of the fact that the lithium nitrate was injected dry into the fruit and had to go into solution in the freed cell sap, its presence was shown in the leaves behind the fruits.

Water relations of this same general sort have been established by a number of other investigators in plants where such deficits do not constitute a stimulus to abscission. Under this category are to be classed Renner's[43] "sätigungsdefizit" and the phenomenon of "incipient drying" described by Livingston and Brown[44] and established in other plants by Lloyd[45] and Edith B. Shreve.[46]

To determine actually the ultimate connection between abnormal water relations of the type noted and the abscission of young fruits has constituted a most difficult problem, and the evidence indicating such a connection has been obtained from several different lines of attack. Although not as conclusive as could be desired, still we believe that it is sufficient to indicate in general the relation between the two. It is hoped that additional evidence can be obtained during the next season, which evidence we were unable to get during our investigation through lack of sufficient equipment and apparatus.

As was mentioned in the description of the East Bakersfield station, this orchard is planted to alfalfa, protected by an efficient windbreak, and heavily irrigated. The noteworthy fact, however, is *that this orchard habitually bears crops in every way comparable to orchards of the same age and general treatment located near the coast.* Although situated only three and one-half miles from the Edison station and having the same exposure, the trees being one year younger, and all conditions similar in every way with the exceptions noted, this orchard

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[43] Experimentelle Beiträge zur Kenntnis der Wasserbewegung, Flora, vol. 103 (1911), pp. 171–247.

[44] Relation of the daily march of transpiration to variations in the water content of foliage leaves, Bot. Gaz., vol. 53 (1912), pp. 309–30.

[45] The Relation of Transpiration and Stomatal Movement to the Water Content of the Leaves of *Fouquieria splendens*, Plant World, vol. 15 (1912), pp. 1–14; Leaf Water and Stomatal Movement in *Gossypium* and a Method of Direct Visual Observation of Stomata *in situ*, Bull. Torr. Bot. Club, vol. 40 (1913), pp. 1–26.

[46] The daily march of transpiration in a desert perennial, Carnegie Inst. Washington, Publ. 194, 1914.

bears heavy crops (pl. 26), and has been profitable ever since it came
into bearing three to four years ago.

The conclusion cannot but be forced that in the exceptions noted
lies the secret of the heavy set of fruits. In order to obtain some idea
of the climatic conditions obtaining within this orchard as compared
with those under Edison conditions we had recourse to what metero-
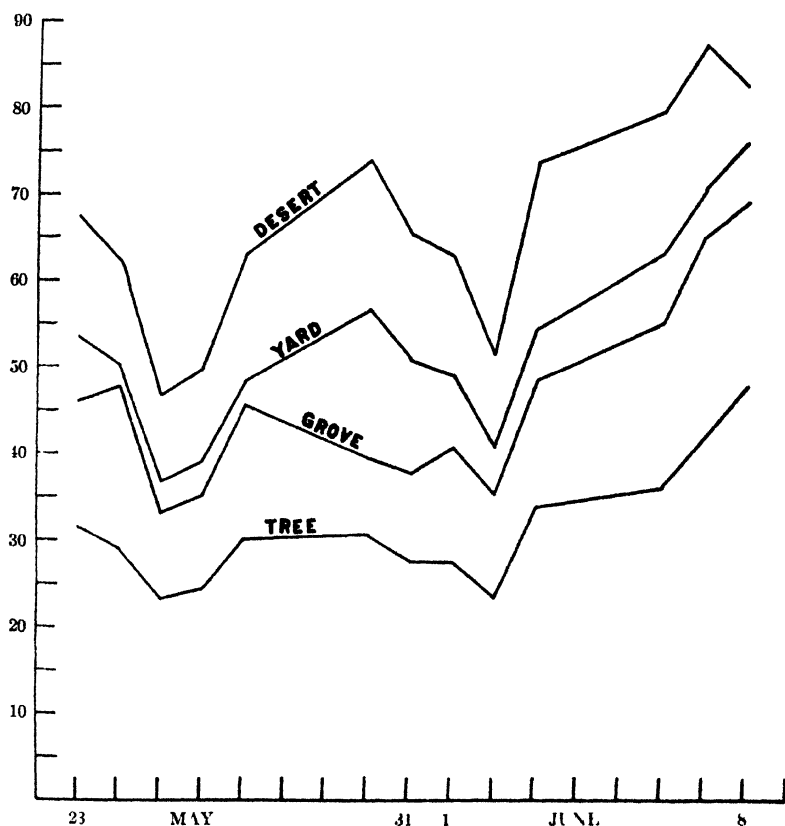
Fig. 2. Comparison of daily atmometer water loss at four different stations
at Edison in 1916. Ordinates, water loss in cc.; abscissae, days of the month.

logical instruments were available to us. While much more significant
results could have been obtained had we possessed more equipment, we
feel that our data, while possibly not accurately quantitative, at least
are qualitative enough to justify our conclusions. Air temperature
and humidity readings were taken by means of a Freiz thermo-hygro-
graph. We were particularly interested, however, in the integration
of all the climatic factors in their effect upon the plant and for this
purpose selected the Livingston white cylindrical porous cup atmo-

meter[47] (pl. 41). We are cognizant of criticisms of this instrument by Briggs and Shantz,[48] but believe that for our purpose it is sufficiently accurate. Due to a lack of a sufficient number of these instruments we were unable to run a series simultaneously at Edison and at East Bakersfield but we did operate them under as nearly similar conditions at the latter place in 1917 as at the former in 1916. Know-
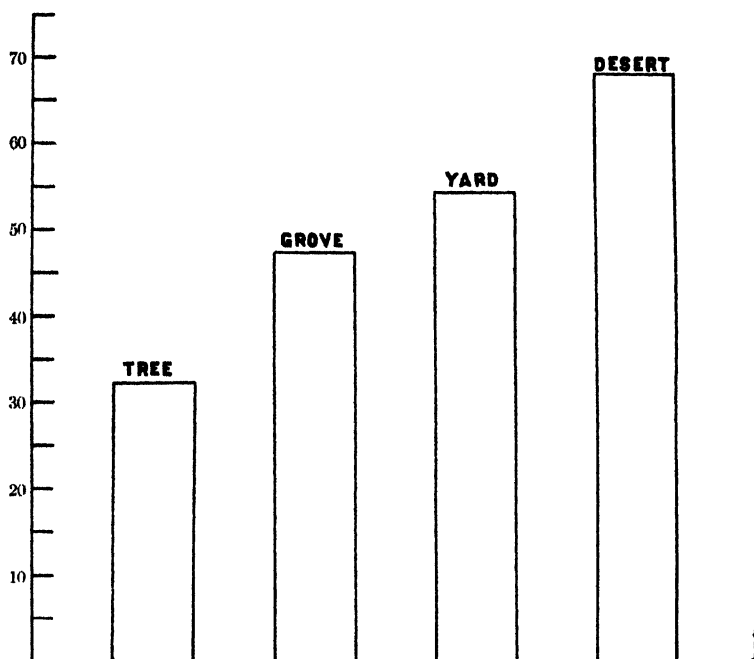
Fig. 3. Comparison of the average daily atmometer water loss from the stations referred to in figure 2.

ing something of the relative harshness of the two seasons, both as reflected in the amount of dropping and in the data taken by the U. S. Weather Bureau observer at Bakersfield, we are able to approximate fairly well the climatic conditions at Edison in 1917 for comparative purposes. The water loss from our different stations at the two localities is well shown in figures 2, 3, 4, and 5 and in table 5.

At Edison our atmometer stations were selected as follows: "Tree" station was located underneath an orange tree near the center of the orchard, about one-half mile to leeward of the edge of the orchard

[47] The Relation of Desert Plants to Soil Moisture and to Evaporation, Carnegie Inst. Washington, Publ. 50, 1906.

[48] Comparison of the Hourly Evaporation Rate of Atmometers and Free Water Surfaces with the Transpiration Rate of *Medicago sativa*, Jour. Agr. Res., vol. 9 (1917), pp. 277–96.

which bordered the desert. "Grove" station was situated in the open orchard midway between the tree just mentioned and its neighbor. "Desert" station was located on the open, bare desert about one-half
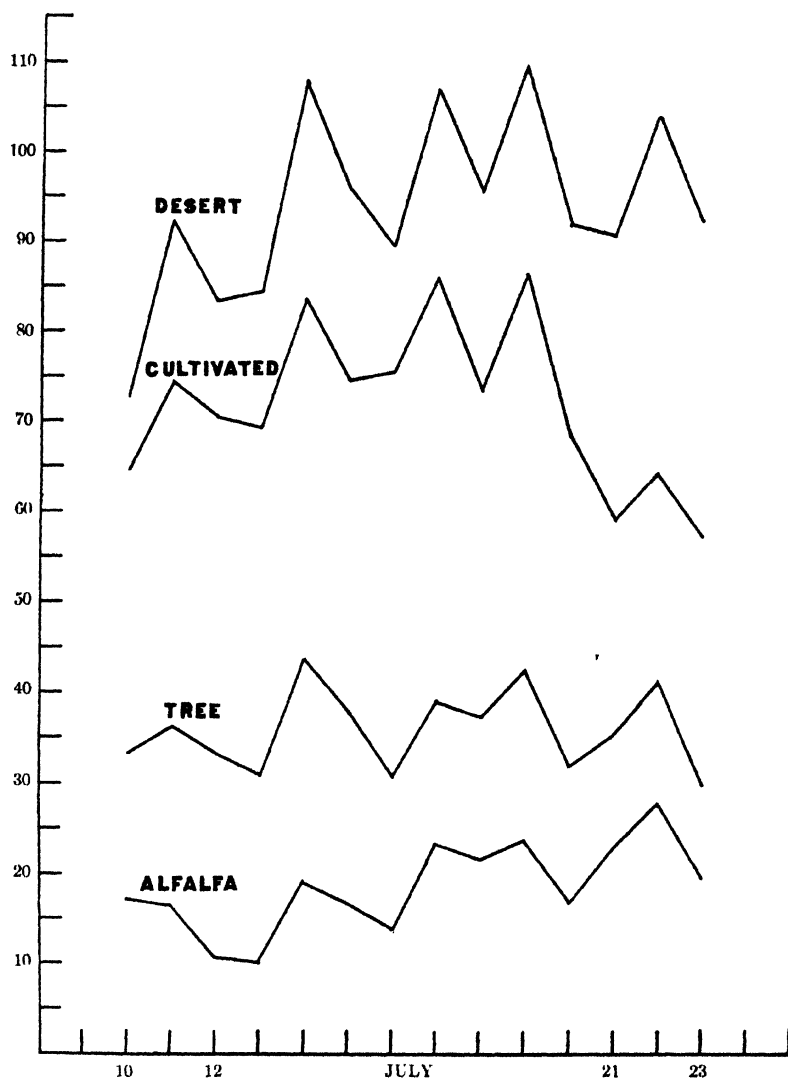
Fig. 4. Daily evaporation from atmometers at four different stations at East Bakersfield in 1917. Ordinates, water loss in cc.; abscissae, days of the month.

mile to windward of the edge of the orchard and many miles to leeward of any irrigated land (pl. 41)). The data accumulated for nineteen days are shown in figures 2 and 3 and table 5.

At East Bakersfield our atmometers were set up at the following stations: "Tree" station was similar to "Tree" station at Edison except that the tree where it was located was in the orchard planted to alfalfa. "Alfalfa" station was located similarly to "Grove" station at Edison but of course was surrounded on all sides by alfalfa,
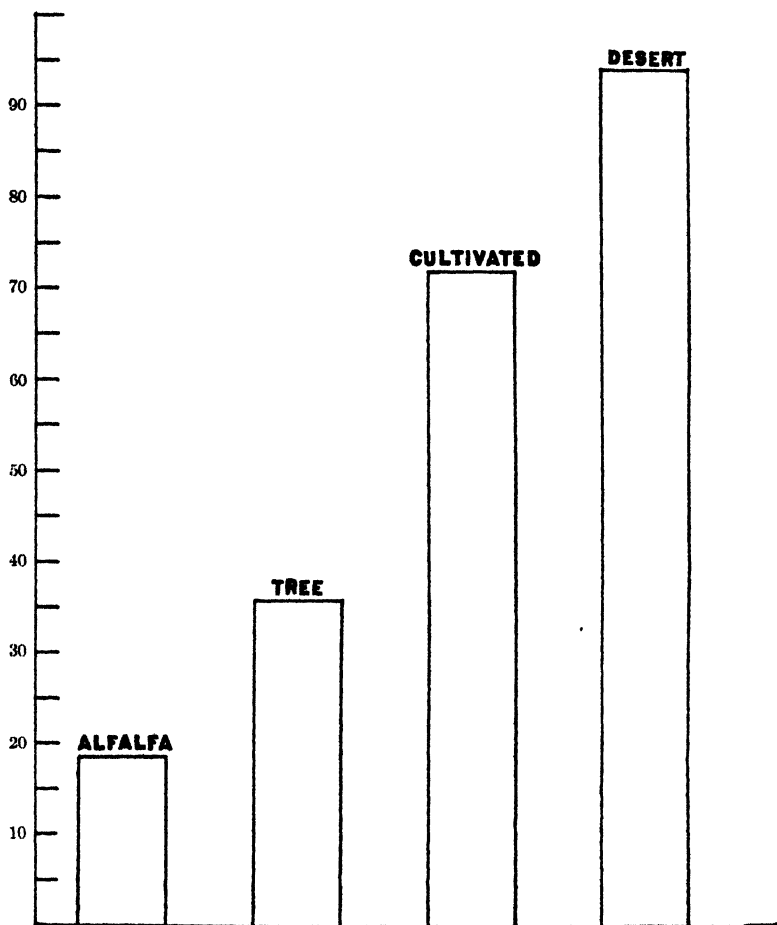
Fig. 5. Average daily water loss from atmometers at the stations referred to in figure 4.

which averaged some twelve to eighteen inches high. "Cultivated" station was located in every respect similarly to "Grove" station at Edison and the two "Desert" stations were similarly situated. The data accumulated for fourteen days are shown in figures 4 and 5 and table 5.

It is at once obvious, looking at the stations, which are in every way comparable, that the critical period in 1917 was considerably more severe than in 1916 (fig. 6), which difference has been pointed out with respect to the yield of the Edison orchard. It is also equally evident that the water loss from the soil and plants has a most profound effect in ameliorating the atmospheric evaporating power and that this effect is cumulative with the direction of the prevailing winds. Thus at Edison the "Desert" atmometer lost an average of 69.1 cc. to 48.1 cc. lost by the "Grove" station and at East Bakersfield the same stations lost water in the ratio of 94.0 cc. to 71.7 cc. At Edison the orchard environment during 1916 was sufficient to cut down the asperity of the climate about 45 per cent, while at the Kellogg place in 1917 it was sufficient to reduce it 31 per cent. The atmometer inside the tree lost only two-thirds of that lost by the instrument at "Grove" station or only 45 per cent of that at the "Desert" station. Thus we can see the marked effect of an orchard in modifying its own environmental complex. It is undoubtedly this influence which the orchard manifests *per se* which explains to some degree why it is that as orchards planted in exposed districts grow older, the percentage of yield increases more than the increase in size of tree. The fact that inside fruit is subjected to an entirely different climate than exposed fruit serves to explain why it is notably of better texture and grade and why it possesses so few large and protuberant navels. We have observed that Navel oranges grown in the University of California greenhouses are of markedly superior texture and navel conformation to those produced outside, where conditions are not so mild or uniform. Again, it is this cumulative modification of the climatic complex following the direction of the prevailing wind which explains the fact that a notably heavier set of fruit occurs on the south and east side of the trees. This condition has been frequently mentioned and was quite marked at Edison in 1917.

But the most striking modifications in climatic conditions are to be seen with reference to the situation at East Bakersfield. Although the Desert station atmometer lost an average of 94.0 cc. the Alfalfa station instrument lost only 18.5 cc. or only 20 per cent as much. Reference to table 5 serves to show that here is a climatic change within a half mile in the San Joaquin desert of the same magnitude as that between Miami, Florida, and Tucson, Arizona. The effect is, of course, largely due to the fact that the alfalfa transpires at a tremendous rate and the atmometer cup at that station was continuously bathed in an
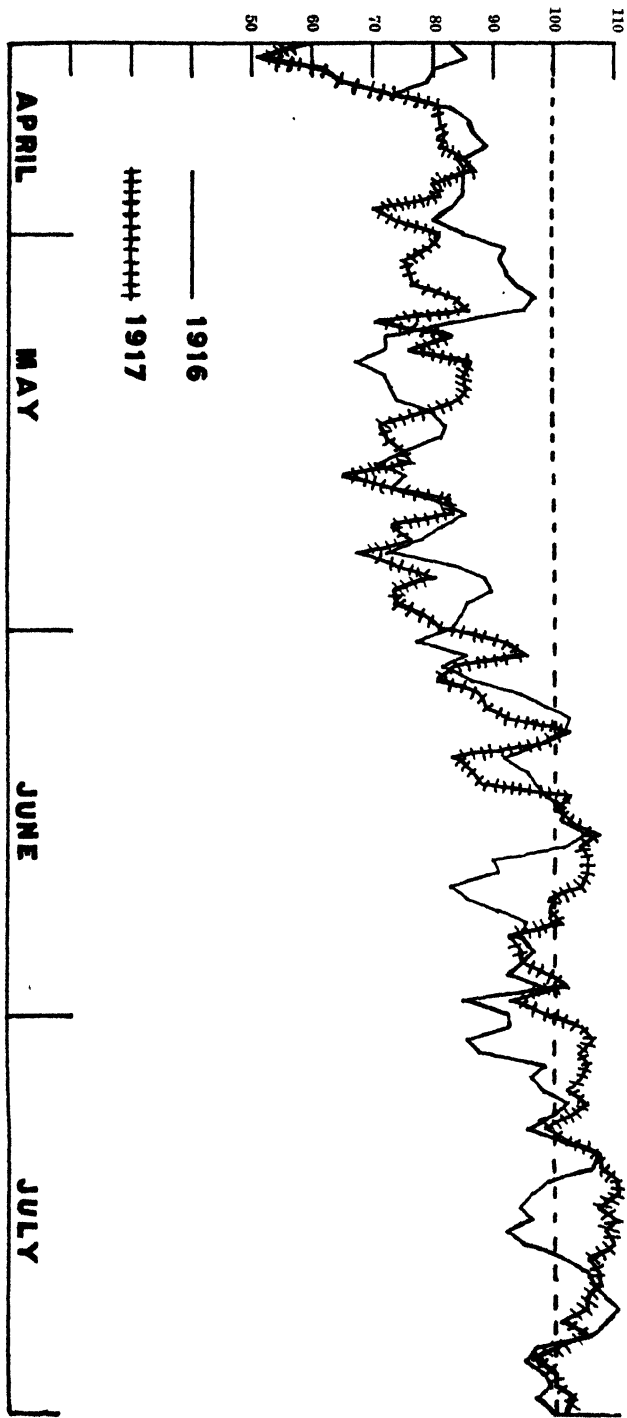
Fig. 6. Maximum daily temperatures for period April 15 to August 1, 1916 and 1917.

almost saturated atmosphere.   The windbreak served to prevent the blanket of moist air from being rapidly dissipated.   The loss from Tree station is seen to be 35.8 cc., or only 30 per cent of that lost by the Desert instrument.   Although the effect of the alfalfa cannot be exerted at any very considerable height above the ground, still it is certain that the orange trees (with the young developing fruits) surrounded by this transpiring alfalfa are literally bathed in a damp atmosphere; at any rate so far as the tree is concerned it is subjected to a very different climate from that which obtains on the desert.   The influence of the alfalfa in modifying the atmospheric humidity can clearly be seen when the crop of oranges is picked, for under these conditions most of the fruit is borne near the ground and less in the tops of the trees.   At Tree station, East Bakersfield, thermo-hygrograph readings were taken for a period of twenty days.   A study of the record for the period of the investigation shows some interesting results.   At no time did the temperature rise above 107° F although in the laboratory, a quarter of a mile away, temperatures of 110° to 112° F were registered several times.   The most significant feature, however, is the relative humidity curve.   The lowest humidity reached was 25 per cent, which occurred at the time that the 107° F temperatures were recorded, July 9 and 21.   The average relative humidity during the day was between 40 and 50 per cent.   In 1916 at Edison we recorded humidities as low as 10 per cent and the average relative humidity was between 25 and 35 per cent.   It is unfortunate that we were not able to obtain simultaneous temperature and humidity readings at the Desert station in 1917, but in view of the fact that the 1917 season has been shown to be much more severe than the 1916 season there is little doubt that in 1917 the relative humidity was somewhat lower and the temperature somewhat higher than in the former season.

We recognize clearly that in agricultural enterprises it is unsafe to rely upon climatic averages.   It is well known that with some crops success or failure depends largely upon the extremes of climatic conditions experienced during a certain critical period in their growth. However, it should be borne in mind that conditions which tend to ameliorate the environmental complex not only raise the general average favorably, but also have a distinct modifying effect upon extremes in weather conditions which may occur.   Indeed, it seems probable that this is the most important effect of the alfalfa and windbreaks in the Kellogg orchard.   It is not so much the higher

average humidity as it is the greater freedom from extreme variation in climatic conditions which serves to enable the young fruits to survive.

As referred to above, the junior author[49] has shown in another place that a marked water deficit occurs both in the young fruits and the leaves under the climatic conditions obtaining at Edison and has suggested that these abnormal water relations furnish the stimulus to abscission. If this be so, then when there is little or no dropping of the fruits and consequently a good crop, such abnormal water relations should not be found. An effort was made at the East Bakersfield station in 1917 to establish such abnormal water relations, but it was found impossible to do so (table 8). Instead of there being a regular

TABLE 8

AVERAGE MOISTURE CONTENT AT DIFFERENT TIMES OF DAY

Kind of material	Average water content in per cent, calculated on basis of dry weight 1916	1917
Normal fruits one-third to three-fourths inch in diameter gathered before noon	260.2	285.3
Same, but gathered after noon	247.0	283.9
Leaves of current season's growth, gathered before noon	164.9	174.9
Same, but gathered after noon	157.2	182.6

decrease in water content of similar leaves and fruits during the day, which is made up during the night, no such relation was found. At East Bakersfield the leaves and fruits, in the first place, averaged somewhat higher in moisture content than those taken at Edison. Secondly, although as nearly similar in every respect as possible, duplicate series showed an absolute lack of uniformity, the variation sometimes being as much as 30 to 40 per cent. Finally, no average decrease in water content either of the fruits or leaves was found to occur during the day. It should be mentioned that irrigation at the Kellogg place is not uniform, relatively small tracts being irrigated at one time and these thoroughly soaked. As it was found inconvenient to take all the leaves and fruits from the same trees it is possible that some of the variation in moisture content noted may be attributed to variations in soil moisture. However, under the marked modification of climatic conditions which has been shown to occur as a result of the management of the orchard, it is believed that such abnormal water relations do not occur, at least to anything like the extent to which they do under the unmodified climatic conditions.

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[49] *Loc. cit.*

As to the ultimate stimulus beyond abnormal water relations we can do little but speculate. Lloyd[50] has expressed the idea that increase in temperature following water deficits may be the ultimate stimulus to abscission. It has long been known that plant parts, when for any reason deprived of a normal supply of water, suffer an increase in internal temperature. In an effort to furnish additional evidence as to the presence of abnormal water relations, as well as to obtain some idea of the temperature changes incident to such water deficits, we took some temperatures of fruits destined to fall, fruits suffering from a water deficit by reason of the fact that the tree was permitted· to suffer for lack of irrigation, and temperatures of normal fruits. These are found summarized in tables 9 and 10. It will be seen that

TABLE 9

INTERIOR TEMPERATURES OF FRUITS, FAHRENHEIT

Hour	Fruit destined to drop	Normal healthy fruit	Air
9	91.8	91.4	91.5
9:20	94.1	91.5	93.2
10	96.3	93.0	95.9
11	100.4	96.9	97.5
12	102.2	98.0	100.4
1	106.5	100.9	105.8
2	110.5	104.9	110.1
3	109.9	107.2	109.0
4	111.9	110.3	110.8
5	111.2	110.3	107.2
5:30	107.6	107.6	106.2
Average	103.8	101.0	101.6

TABLE 10

INTERIOR TEMPERATURES OF FRUITS, FAHRENHEIT

Hour	Fruit suffering from drought	Normal healthy fruit	Air
8	87.3	86.9	90.1
9	91.4	90.5	92.1
10	95.5	95.0	97.5
11	98.6	97.2	100.2
12	102.9	100.4	103.6
1	104.2	103.5	105.2
2	104.9	104.0	107.6
3	106.2	105.8	107.6
4	104.0	104.0	104.0
5	101.3	101.3	101.6
6	98.6	98.6	98.2
7	93.2	93.2	94.1
Average	99.0	98.2	100.1

[50] *Loc. cit.*

the normal fruits average somewhat lower in temperature than the air, and in turn those destined to drop are somewhat higher in temperature than the air. Fruits permitted to suffer for lack of water show a temperature approximately that of the air surrounding them. It may be that increase in temperature due to water deficits is the ultimate stimulus to abscission, still it should be pointed out that the increases in temperature as recorded by us are of a much smaller magnitude than the daily range in temperature changes. We are fully aware, of course, that strictly accurate temperatures of plant tissues can only be obtained by thermo-electric means, the mercury thermometer being too subject to fluctuation and variation for very delicate work.

Factors Operative in Causing Water Relation Strains

It is of course obvious that, given a plant transpiring a certain amount of water vapor daily, unless there be a sufficient water supply in the soil within reach of the absorbing roots to make up for that lost by the plant and in addition supply enough for its metabolic processes, water deficits of the kind mentioned must eventually occur. That under these conditions such do occur and that they are followed by an abnormally severe shedding of the young fruits when in the critical period, is the observation of the authors and the experience of many growers. In the season of 1916 the junior author had under observation a ten-acre block of orange trees in the Oroville district which had been top worked to the Washington Navel variety five years previously. They bloomed very heavily and set an excellent crop. Through an accident to the irrigation system preventing a sufficient supply of water these trees were allowed to suffer for lack of water at the time when the young fruits were about one centimeter in diameter. At the time of irrigation several days later the fruits had not fallen and it was hoped that the crop could be saved. Within a week practically every fruit was shed, although the trees looked well and had entirely recovered from the drought.

Observations, confirmatory in every respect to those given above, were made on a row of trees at the Kellogg place in 1917. These trees were permitted to suffer for lack of irrigation. Although the only trees in the row which at the time bore fruits in the critical stage were of the Valencia variety, which variety is much less subject to shedding than the Washington Navel, still within a week after the application of the water many of the young fruits had fallen. The desirability of

a proper moisture supply in the soil at the blooming and setting period is reflected in the practice of many growers who irrigate their orchards heavily at such times as well as during the periods of hot, dry north winds.

In this connection it should be noted that Fowler and Lipman[51] have recently shown that under conditions of a soil moisture supply somewhat below the optimum the visible effects upon the citrus tree are a great deal less than under conditions of the same percentage above the optimum moisture content. In other words, these authors have shown that the citrus tree does not exhibit the effects of a deficient soil moisture supply to the same extent that it does an excess of moisture in the soil. It may well be, therefore, that many of our citrus orchards are underirrigated and the irregular water relations above discussed accentuated by reason of this fact. The authors feel that many of the orchards studied in this investigation would probably do better with heavier irrigation. Manifestly it would be useless to attempt methods of modifying the climatic complex with the end in view of cutting down daily water deficits, if the soil moisture supply is deficient. Therefore, the grower should first make certain that sufficient soil moisture is available.

It has long been known that the presence of sufficient moisture in the soil is not conclusive evidence that the plant is enjoying optimum moisture conditions. Plants inhabiting salt marsh regions possess their xerophytic adaptations by reason of the fact that although growing with their roots in water or mud they are unable to obtain water in any large amounts and are forced to economy in the use of it This inability to absorb water has been traced to the ratio between the osmotic concentrations of the soil solution and the cell sap of the roots, and such a condition is called "physiological drought." Physiological drought may be induced by the inhibition of absorption through the action of factors other than the osmotic concentration of the solutions involved.

Among the most important factors conditioning absorption is that of aeration It has long been known that when grown in water cultures many plants make very unsatisfactory growth. Hall, Brenchley, and Underwood[52] have recently shown that this unsatisfactory growth is due to lack of aeration and can be remedied by passing a stream of

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[51] Optimum Moisture Conditions for Young Lemon Trees on a Loam Soil, Univ. Calif. Publ. Agr. Sci., vol. 3 (1917), pp. 25–36.

[52] The Soil Solution and the Mineral Constituents of the Soil, Jour. Agr. Sci., vol. 6 (1914), pp. 296–301.

air through the solution.   The economic applications of this principle are many, but are of course particularly evident in regions where through special conditions lack of soil aeration is emphasized, as is the case in certain parts of India.   The soil is naturally very heavy and easily packed by the torrential rains.   Lack of aeration is accentuated during certain portions of the growing season by the occurrence of monsoons and tropical rainstorms of great severity.   Howard[53] has shown most conclusively that under these conditions the production of the gram or chick-pea, *Cicer arietinum,* grown to the extent of over eighteen million acres, is absolutely conditioned by the soil aeration. If the soil is permitted to become packed by summer rains and the air supply cut off, the plants wilt down with water actually standing on the surface of the soil.   Absorption is cut down to practically nothing, while transpiration is not reduced in the same ratio, resulting in ultimate wilting.   While not extensive, all the experimental data available on the production of this crop in California show this same intolerance of lack of soil air.   Howard has shown this same condition affecting fruit trees and other crops, among which is the indigo plant. Free[54] has shown that with *Coleus blumei* "even a very small decrease of oxygen below that normal to the atmosphere is injurious to the plant.   Thus a plant, the roots of which were supplied with gas consisting of 75 per cent air and 25 per cent nitrogen, was injured within three days and killed within 45 days.   With lower oxygen content in the soil atmosphere injury and death are still more prompt."   In many cases the lack of aeration is first evidenced by the shedding of the leaves and flowers.   Soils of arid regions in general are well aerated, and especially soils of open structure such as sands and sandy loams.   Therefore it is not likely that lack of soil aeration is the factor conditioning absorption of water by citrus trees.   However, this problem is now under investigation and will be reported on later.

Under most conditions of lack of aeration not only is oxygen deficient but carbon dioxide is present in excess.   The experimental data available seem to indicate that while in general lack of oxygen and excess of carbon dioxide in the soil atmosphere are detrimental, there is no set rule.   Cannon,[55] and Livingston and Free[56] have shown

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[53] Soil Aeration in Agriculture, Agr. Res. Inst. Pusa, Bull. 61, 1916.

[54] Cannon, W. A., and Free, E. E., The Ecological Significance of Soil Aeration, Science, n.s. vol. 45 (1917), pp. 178–80.

[55] On the Relation between the Rate of Root-Growth and the Oxygen of the Soil, Ann. Rep. Dir. Dept. Bot. Res., Carnegie Inst. Washington, Yearbook 15 (1916), pp. 74–75.

[56] Relation of Soil Aeration to Plant-Growth, *ibid.,* p. 78.

that there is considerable variation in this respect, some plants, such as *Salix* sp., growing and thriving in a soil containing no oxygen. Apparently the limiting concentrations of these gases must be worked out for each plant separately.   As to the specific effect of lack of oxygen and excess of carbon dioxide resulting in changes in absorption rate little is definitely known.   The first effect seems to be a slowing down of growth, which in turn being ordinarily accompanied by the imbibition (in the case of the embryonic growing regions of the root) of water in considerable amounts, reduces absorption markedly.   The exact relation between growth and absorption is not well understood at the present time; but it has been shown by MacDougal[57] and others of the Carnegie Institution that growth of embryonic tissues is mainly accomplished by the imbibition of large quantities of water.   It can be readily seen, therefore, that if conditions are unfavorable for growth, imbibition and absorption must necessarily be reduced.

Another factor which acts in a very similar way to lack of aeration, and one little appreciated up to the present time. is that of soil temperature.   Every year adds more confirmatory evidence to prove that the temperature relations of physiological processes follow certain typical curves, which seem to be identical or closely related for processes of the same fundamental nature in different organisms.   The effects of temperature on physiological processes, both in plants and animals, have been investigated by many workers and in general a modified curve of the Van't Hoff type has been obtained where the most careful work has been done.   In such curves several cardinal points can be determined, namely. the minimum temperature at which the process goes on, the maximum temperature beyond which the process no longer continues, and the optimum temperature at which the process is most active.   This last term has been superseded by what is known as the maximum rate temperature, representing that temperature above which the rate is ultimately decreased and below which the same occurs. Blackman[58] has shown that the term optimum temperature is indefinite. since at certain temperatures physiological processes are very rapid for a time but then slow down, due to the introduction of a time factor.   The maximum rate temperature is that temperature above which a time factor is introduced resulting in an ultimate retardation of the process.

These cardinal temperatures differ somewhat for different processes but still more markedly do they differ for the same process in different

57 *Ibid.*, Yearbook 15, 1916.

58 Optima and Limiting Factors, Ann. Bot., vol. 19 (1905), pp. 281–95.

organisms. Thus Howard[59] has shown with wheat that at the germinating period a fall of 10° to 12° F from 84° to 72° may mean the difference between success and failure in obtaining a stand, since the growth rate is almost inhibited at the former temperature. On the other hand, Cannon[60] has shown that the maximum rate temperature for the mesquite, *Prosopis velutina,* and *Opuntia* is about 93° F. Tobacco is another plant which thrives in hot soils. Leitch[61] has shown that for the garden pea, *Pisum sativum,* 85° F is the maximum rate temperature and above 110° F no growth whatever occurs. Apparently, as in the case of the aeration factor, no general rule for these cardinal temperatures can be laid down. They must be determined for each plant separately. Since growth conditions absorption we are justified in assuming that the cardinal temperatures for growth are approximately those for absorption.

The genus *Citrus,* as mentioned elsewhere, is native to the tropics, where it grew in the shade of other trees. Under these conditions the soil was damp and soil temperatures certainly not high. It therefore seems logical to assume that the temperatures favorable for root growth in *Citrus* are not very high. As grown under clean cultivation in the arid southwest we believe that the absorbing roots are subjected during a certain portion of the day to temperatures above the optimum and that during such periods absorption is actually reduced.

TABLE 11

SOIL TEMPERATURES (F.) AT EDISON, JUNE 7, 1916

Hour	A M 9 15	10·15	11 15	P M 12·15	2:15	3.15	4·15	5:15
Six-inch dust mulch	80.6	84.2	88.2	92.3	94.1	96.0	99.5	99.0
First 6 inches	77.0	78.3	80.0	84.2	89.6	88.8	88.6	87.0
Second 6 inches	77.0	76.1	76.1	78.0	82.4	82.4	82.4	80.6
Third 6 inches	76.1	75.0	75.0	75.3	79.2	77.2	78.3	78.0
Fourth 6 inches	74.3	74.3	74.6	74.6	77.2	76.6	77.0	77.0
Six-inch dust mulch in shade of tree	71.6	73.6	74.3	81.0	83.7	82.5	82.2	82.2

To obtain an idea of the soil temperatures prevailing in the upper two feet of soil in 1916, a comparatively cool season, we made a series of hourly readings at six-inch intervals. These may be found summarized in table 11. This table shows that during the afternoon

[59] Influence of Weather on Yield of Wheat, Agr. Jour. India, vol. 2 (1916), part 4.

[60] Relation of the Rate of Root Growth in Seedlings of *Prosopis velutina* to the Temperature of the Soil, Plant World, vol. 20 (1917), pp. 320–33.

[61] Some Experiments on the Influence of Temperature on the Rate of Growth in *Pisum sativum,* Ann. Bot., vol. 30 (1916), pp. 25–46.

the temperature of this upper layer of soil does not fall below 75° F. As was brought out previously, under clean cultivation practices the absorbing roots of citrus trees are largely located in the upper two feet of soil (pl. 42). It therefore seems quite probable that during the afternoon at the very period when water loss by transpiration is greatest, absorption is inhibited by high soil temperatures. A study of the cardinal temperatures for absorption by citrus roots, which is expected to throw considerable light on this question, is now under way and will be reported on later.

But granted that a condition of physiological drought existed, due to the action of the factors just discussed, still the citrus tree might
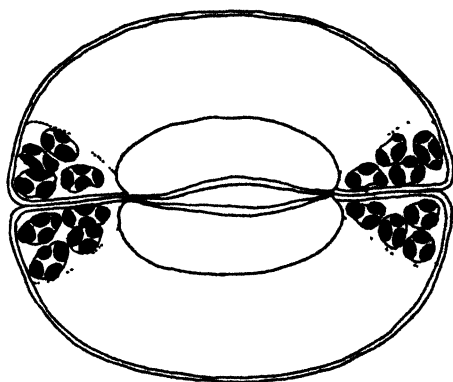
Fig. 7. Citrus stoma showing maximum opening. From orange leaf just reaching full size.

maintain itself in a proper water balance were it not for the fact that it is not provided with efficient means of conserving its water by regulating its loss through transpiration. A preliminary study of the relation of cuticular transpiration to stomatal water loss has brought out the fact that from 40 to 50 per cent of the water loss from citrus leaves occurs through the upper epidermis which does not contain stomata. These studies have shown that the young leaves are more efficient than the older leaves but that even the youngest leaves lose as much as 25 per cent of their water through the upper epidermis.

A study of the stomatal condition in citrus leaves has brought out some interesting facts. By the use of Lloyd's method[62] the amplitude of stomatal movement was studied. It was found that very early in the life of th leaf the stomata lose their power of opening and closing and remain practically closed thereafter (fig. 7). In some cases the

[62] Physiology of Stomata, Carnegie Inst. Washington, Publ. 82 (1908), p. 26.

closure is not complete and the stomata remain slightly open. Heil-bronn[63] has established this same condition in the leaves of the *Camelia*. It is interesting to note in this regard the results obtained by Shreve[64] in a study of the transpiration of rain-forest plants carried on in Jamaica.

The true stomatal transpiration is thus found to be from 42 to 48 per cent of the total water loss of the leaf. The close relation of transpirational behavior to evaporation is thus shown to have its basis in the fact that rather more than half of the water-loss of the plant goes on through the epidermal surfaces. . . . The amplitude of stomatal movement in rain-forest plants under shade conditions has been found to be relatively small. . . . The weakness of the move-
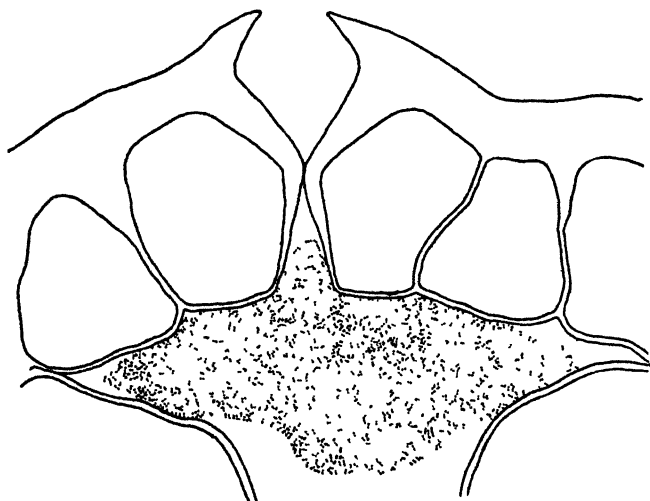
Fig. 8.   Cross section of stoma from old coriaceous orange leaf.   Note resinous deposit in the substomatal cavity.

ments, together with the high cuticular water loss, serves to give the stomata a very negligible rôle as regulators of transpiration rate, particularly during the daylight hours.

It was found that a varying percentage of citrus stomata are occluded by deposits of a resinous, gummy nature (fig. 8) in the substomatal cavity. Haberlandt[65] points out that physiological degeneration of stomata takes place in a number of shade-loving hygrophytes, doubtless because members of these ecological classes never require much protection against excessive transpiration   Therefore it can be readily appreciated that the citrus plant has relatively little control

[63] Ber. d. deut. bot. Ges., vol. 34 (1916), pp. 22–31.   (Cited from Exp. Sta. Record.)

[64] The Transpiration Behavior of Rain-forest Plants, Ann. Rep. Dept. Bot. Res., Carnegie Inst. Washington, Yearbook 12 (1913), pp. 74–76.

[65] Physiological Plant Anatomy (London MacMillan, 1914), p. 272.

over its water loss.   This condition itself constitutes strong evidence of its tropical origin.

If there be any regulatory action upon transpiration it should be brought out in a study of the transpiration curve as compared to the evaporation curve.   These two curves for a typical day in July are shown in figure 9, and it will be seen that the general form is very similar and that the maxima of the two were reached at the same
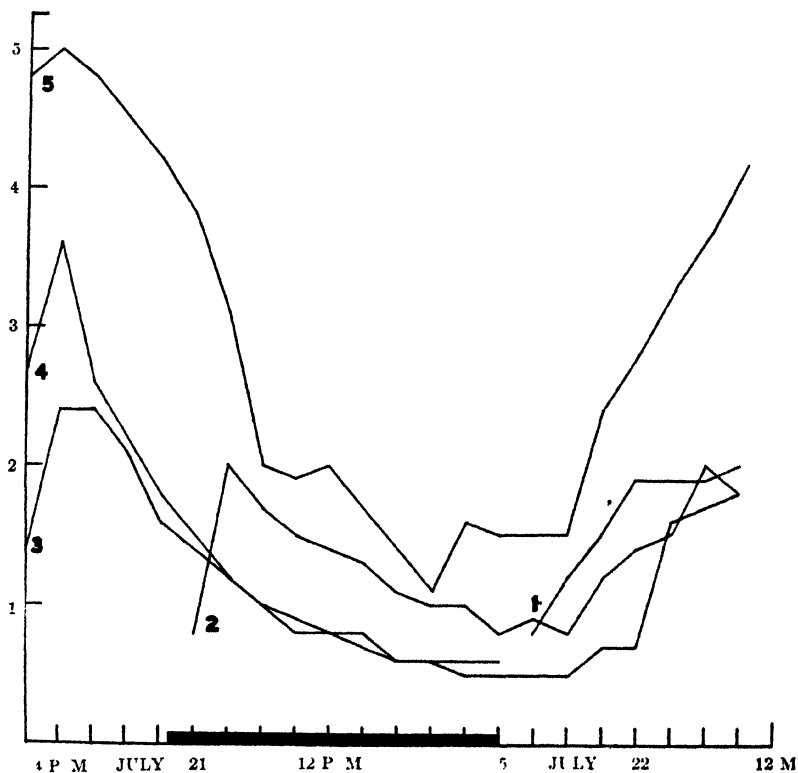
Fig. 9.   Comparison of *Citrus* transpiration curves with the evaporation curve for the same period.   Nos. 1, 2, 3, and 4 are transpiration curves obtained by the potometer method.   No. 5 is the evaporation curve obtained from a Livingston white cylindrical porous cup atmometer.   Ordinates represent water loss in cc.; abscissae, hours of the day.

period.   Were there any regulatory action the transpiration curve should reach its maximum some time before the evaporation curve.

SUSCEPTIBILITY OF CITRUS VARIETIES TO ABSCISSION

It is well known that when grown under similar conditions the Valencia variety of orange and the pomelo do not shed the young fruits in anything like the same proportion as the Washington Navel.

If the stimulus leading to abscission be abnormal water relations, why then do not these two other members of the genus shed their fruits to the same extent as the navel variety? Our observations made in the field in orchards where these varieties are mixed have shown that such is not the case, and experiments performed in our laboratories have shown that abscission is much more easily induced in the navel variety than in the others. Shoots bearing flowers and young fruits of each variety have been placed in moist chambers and kept at room temperature. In the case of the navel variety abscission of all the flowers and fruits has invariably occurred within sixty hours, while in the Valencia variety and with lemons frequently no abscission occurred within five to eight days. Apparently the navel variety is much more susceptible to stimuli which lead to abscission. In this connection it seems desirable to call attention to the fact that other investigators have found in the case of hybrids abscission is much more prevalent and much more easily brought about than in the case of the parent varieties. Thus Goodspeed and Kendall[66] have shown that in the case of certain tobacco crosses in which only a small proportion of the ovules are normally matured and capable of fertilization, which condition obtains in the navel orange variety, practically all the flowers and young fruits are abscissed. May not this sensitiveness to stimuli which cause abscission constitute further evidence that the Washington Navel variety is of hybrid origin?

Methods of Amelioration

From the preceding discussion it is obvious that all methods of preventing the June drop of our present strains of Washington Navel oranges must be in the nature of modifying the environmental complex either above ground, below ground, or, as is usually the case, both.

If the cause underlying these water deficits lies in the asperity of the atmospheric complex then practices tending to ameliorate climatic conditions should work out to produce heavier crops. Such has been found to be the case. The planting of windbreaks to prevent the dissipation of blankets of moist air; a moderate winter pruning to reduce the total leaf surface area; and the planting of intercrops, such as alfalfa, sweet clover, or buckwheat, which transpire large amounts of water vapor; all these are methods of modifying the atmospheric environmental complex.

[66] On the Partial Sterility of *Nicotiana* Hybrids made with *N. sylvestris* as a Parent, III: An Account of the Mode of Floral Abscission in the F₁ Species Hybrids, Univ. Calif. Publ. Bot., vol. 5 (1916), pp. 293–99.

In this connection it should be emphasized that the beneficial effect of a summer cover crop does not seem to be due so much to the raising of the average humidity as it does to the buffer effect which it plays when sudden extremes in climatic conditions are experienced. The increase in the average humidity occasioned by the use of a summer cover crop is probably considerably smaller than the difference which may exist from one season to the next. It does not seem so important that the average humidity has been increased somewhat by its use as that when sudden hot, dry spells are experienced their effect is modified by the use of such a crop. This would seem also to explain the effect of the straw mulch which of course does not affect the atmospheric humidity to any extent.

If the limiting factor causing these abnormal water relations be high soil temperatures then methods of orchard management which will reduce such temperatures may be expected to result in heavier crops. Such practices as mulching and the growing of intercrops are known to reduce the soil temperatures. Moreover, such practices in many cases have resulted in notably heavier yields. The junior author had under observation a twenty-acre orchard in the Oroville district in the 1917 season. This tract was planted out to purple vetch in the late fall and was not plowed until the following June. It was heavily irrigated during April and May. Although situated in a most exposed position this orchard bore a much better crop than any other orchard in this district, notwithstanding the extremely heavy fall of fruits experienced in this season. It is possible that the heavy crops borne at the Kellogg place are partly attributable to a reduction in soil temperature during the growing season.

Some data have been published on the effect of straw mulches on the setting of Navel oranges. Briggs, Jensen, and McLane[67] report as follows:

The set of fruit was very light throughout the Riverside district in 1915, owing apparently to cold weather following the bloom. In the Sunny Mountain tract, where the mulched basins were first installed in 1913, the average number of oranges per tree on the check trees in 1915 was 116, while on the mulched-basin tree, the average number of oranges per tree was 281, or two and one half times as many as on the check trees.

Similar results are reported from other tracts. It should be remembered, however, that the trees used in this work were not healthy but were badly mottled, and the increased setting may be attributable to

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[67] The Mulched-Basin System of Irrigated Citrus Culture, U. S. Dept. Agr., Bull. 499 (1917), p. 30.

their improved health brought about by better soil moisture and humus conditions as well as improved temperature conditions. It has not yet been satisfactorily shown that the mulched-basin system alone will reduce the amount of drop on healthy trees, although in the light of the discussion above we believe it probable.

The determination of the specific factor, if it be a single factor, which produces the abnormal water relations established, is yet to be made. It is hoped that investigations planned for the coming season may aid in solving this question. The orchard management practices described above which result in heavier crops, unfortunately for investigational purposes, involve the modification of both the aboveground and under-ground environmental complex.

The fact that by proper means man is able to change the climatic conditions from those obtaining at Tucson, Arizona, to those at Miami, Florida, within the space of a half mile, augurs well for the successful control of the June drop. Measures of an anticipatory nature lie in the proper selection of the site before planting. The exposure to prevailing winds, the nearness to large irrigated tracts, the possibility of planting windbreaks; all these should be considered in the selection of a site for a Navel orange grove. Growers should accustom themselves to thinking of climate not in terms of great valleys and states but in strictly local terms. As has been pointed out above, the judicious selection of the site, coupled with proper methods of orchard practice, make it possible to secure marked modifications in our arid climate. The question of the advisability of the measures suggested is purely one of farm economics and does not lie within the province of this paper.

In view of the relatively small amount of shedding which is connected with the *Alternaria* fungus alone and because of the peculiar manner of infection the authors are led to believe that spraying with fungicides for the June drop will hardly pay for the materials and labor involved.

Another promising line of investigation looking toward control of the June drop lies in the selection and propagation of 'dry heat resistant strains of the Washington Navel variety. This variety, it is well known, is constantly throwing off bud sports or mutations and it is entirely possible that mutations may arise which are less sensitive to abscission stimuli, but at the same time satisfactory otherwise. Every grower should be on the lookout for such strains.

SUMMARY

1. Citrus trees as grown in the interior valleys of the arid southwest are subject to an environment entirely abnormal to them in their natural habitat.

2. Moreover, the principal variety grown in these regions, the Washington Navel orange, is itself decidedly erratic and unstable.

3. Among other troubles incident to the abnormal climatic conditions is that heavy dropping of the young fruits, with consequent light crops, known popularly as the June drop.

4. A study of the shedding has established the fact that it constitutes true abscission, involving the separation of living cells along the plane of the middle lamellae.

5. Exhaustive investigations as to the stimulus or stimuli responsible for the abscission have narrowed them down to two: a fungus, *Alternaria citri* E. and P., and climatic conditions.

6. It is considered highly probable that a certain varying per cent of the drop, occurring relatively late in the season, is brought about by the stimulation of this fungus, which is also responsible for a black rot of those infected fruits which remain on the trees to maturity.

7. This fungus is of very wide distribution and infection of the young fruits is made possible through the peculiar structure of the navel orange.

8. The amount of infection is dependent upon weather conditions and the more or less fortuitous configuration of the navel end of the young fruits.

9. On account of the peculiar manner of infection and the relatively small amount of shedding due to the fungus, spraying will probably not pay for the labor and materials involved.

10. By far the greater part of the shedding, which occurs earlier in the season, is due to a stimulus to abscission arising from daily water deficits in the young developing fruits, resulting from the asperity of the climatic complex to which the trees are subject.

11 The principal factor in causing these abnormal water deficits lies in the fact that citrus trees are not adapted to withstanding the heavy water loss incident to the desert conditions under which they are grown. The amplitude of stomatal movement is small and cuticular transpiration very high.

12. It is further believed that under the prevalent clean cultivation practice, the soil temperatures during a part of the day are so high as

to result in the inhibition of absorption at the very time of day that water loss by transpiration is greatest.

13. It has been found possible to modify climatic conditions in an orchard so as to set crops in every way comparable with those produced in much more climatically favored citrus districts.

14. Under these modified climatic conditions the abnormal water relations referred to apparently do not occur.

15. Practical means of amelioration lie in heavier and more frequent irrigation, the planting of intercrops, mulching with straw and other materials, protection by means of windbreaks, and a reduction of leaf area by moderate winter pruning.

16. Measures of an anticipatory nature lie in the judicious selection of the site for the orchard with reference to its exposure, nearness to large irrigated bodies of land, and other features calculated to ameliorate climatic conditions.

17. Orchardists should be on the lookout for mutant strains which are dry heat resistant and satisfactory in other features.

EXPLANATION OF PLATES

PLATE 25

The Navel orange orchard of the Edison Land and Water Company, where much of the experimental work was done.

Part of the Kellogg orchard at East Bakersfield, showing heavy stand of alfalfa (just cut) between trees and also heavy crop of fruit. Photographed November 25, 1917.

1

PLATE 28

Nearer view of same tree, showing details of heavy bloom.

PLATE 29

One branch with leaves removed, showing large number of buds produced.

PLATE 30

Typical abscissed fruits. Those to the right abscissed at the base of the
pedicel, those to the left at the base of the ovary. The two in the center are
healthy fruits picked from the tree for comparison.

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[SCOTT HODGSON, PLATE 3]
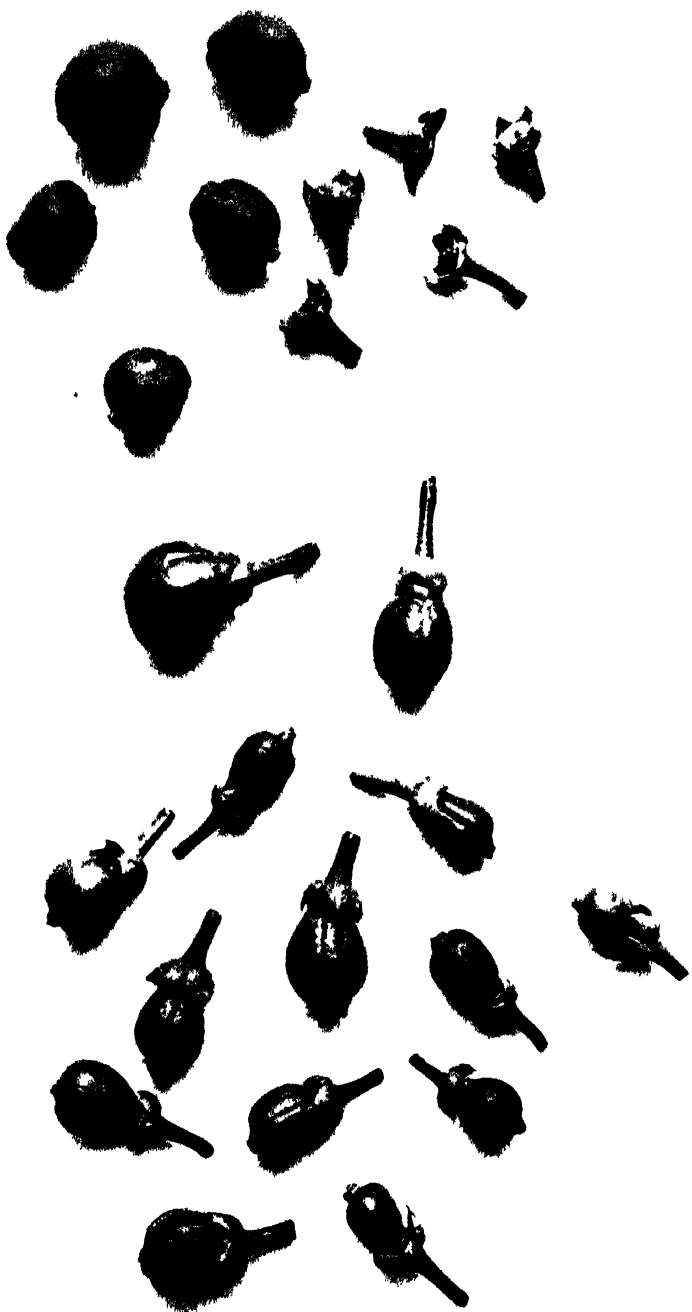
PLATE 31

Small dead orange persisting though abscissed both at base of ovary and pedicel. Large fruit safely through both abscission periods. The dead style abscissed much earlier but was retained in position by the ragged nature of the break.

PLATE 33
Terminal and axillary fruits.

PLATE 34

Apical end of ovary of Navel orange just after the style has been shed. Enlarged 10 diameters. Notice the ragged condition of the stylar scar.
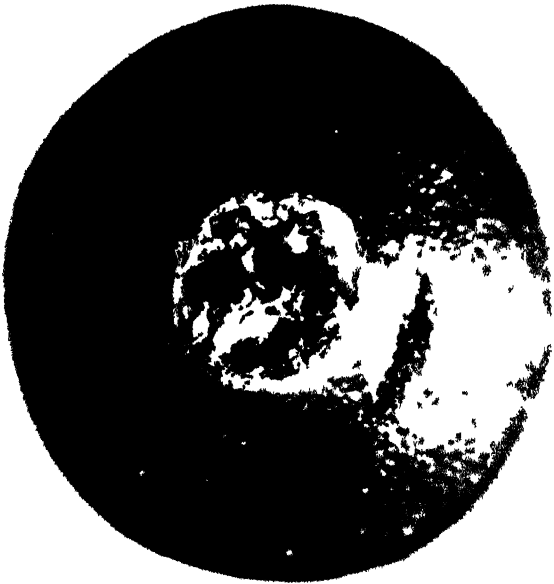
PLATE 35   .

Large late drops showing discolored area beneath the navel, caused by infection with *Alternaria citri*.
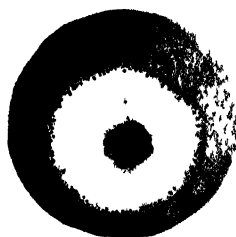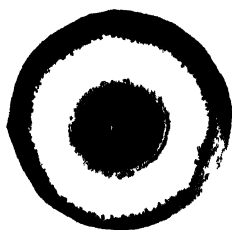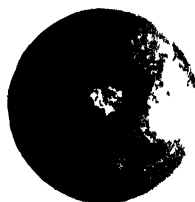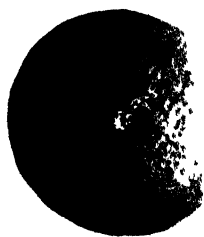
PLATE 36

Photomicrograph of *Alternaria citri,* showing the spores borne in long chains.

PLATE 37

Young Navel oranges, showing the ragged break of the style. Enlarged 2 diameters.
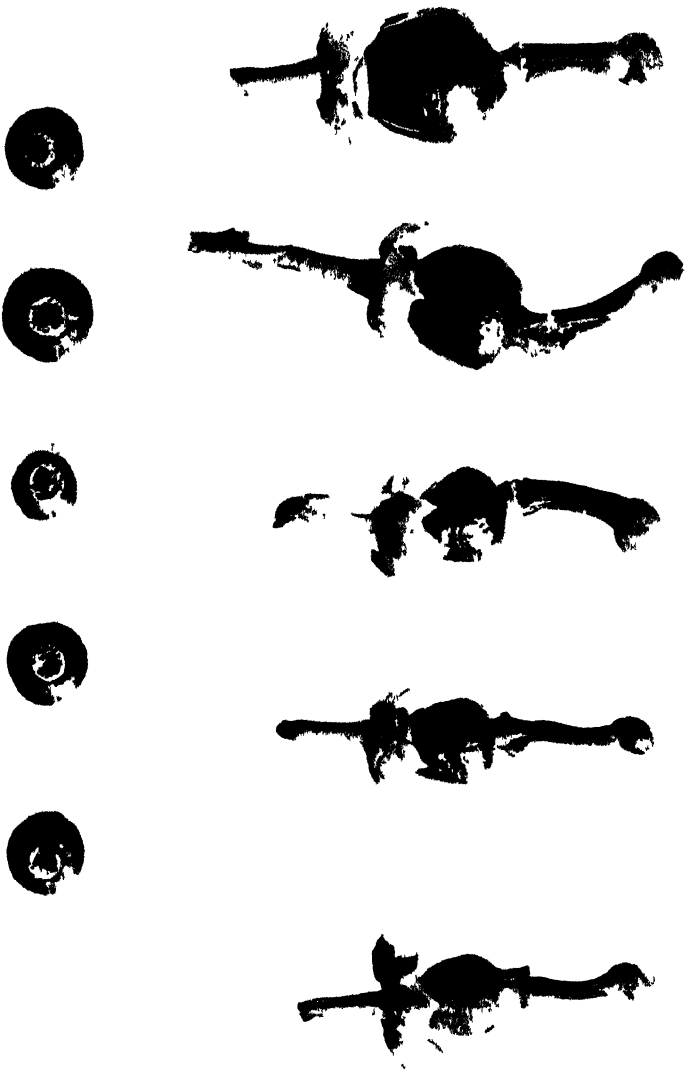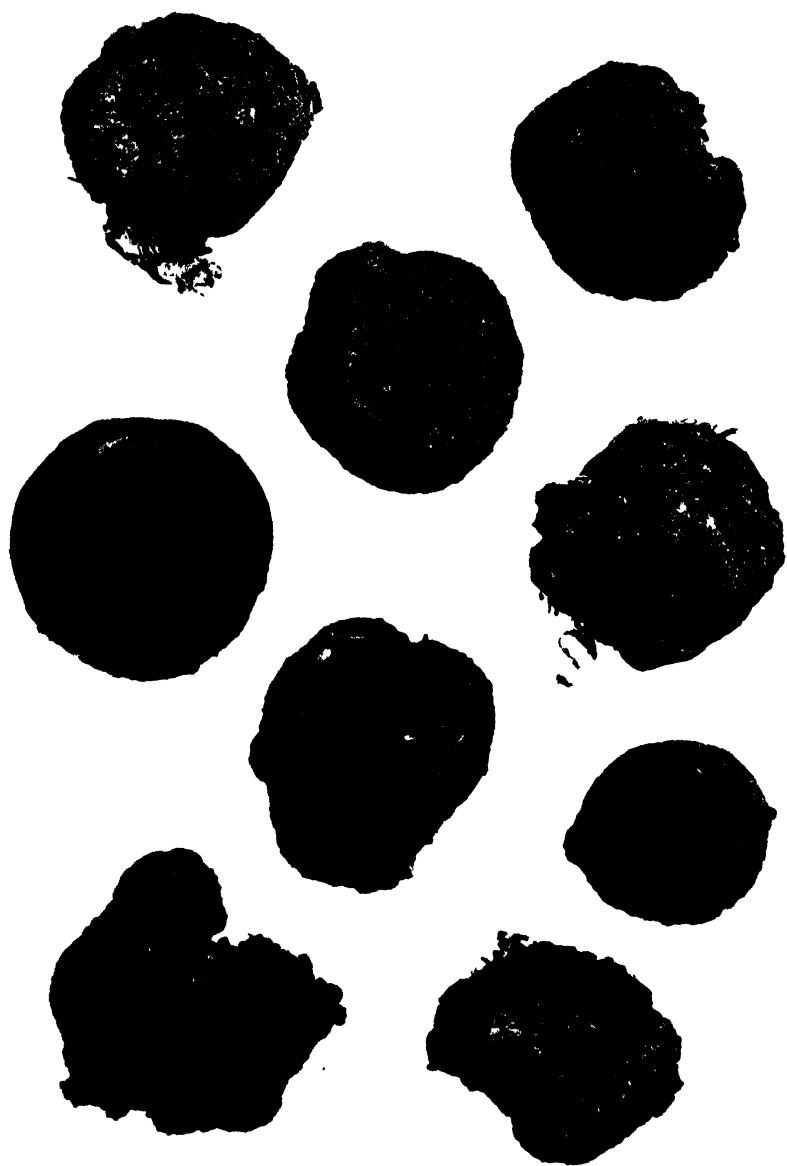
PLATE 40

Showing the method of enclosing orange trees under the tents of cheesecloth in order that bees may be included in one and excluded from the other. The tree in foreground shows the method of covering inoculated flowers with paper sacks.

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PLATE 41

The Livingston white porous cup atmometer as set up at our Desert station.

PLATE 42

Distribution of orange roots by six-inch layers at Edison station. Clean cultivation.

ARE SOILS MAPPED UNDER A GIVEN TYPE NAME BY THE BUREAU OF SOILS METHOD CLOSELY SIMILAR TO ONE ANOTHER?

BY

ROBERT LARIMORE PENDLETON

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CONTENTS

FOREWORD

It is due the author, as well as to the undersigned, that a few words be said by way of preparing the reader for what follows in this paper. It will be observed, first, that the manuscript was, for an unusually long time, in the printer's hands. Those who appreciate, as few do today, the great rapidity with which the theories and the methods in soil and plant study change, will readily catch the significance of the foregoing sentence. Much of the work done by Mr. Pendleton and some of the methods used may now properly be considered obsolete, or, conservatively speaking, at least obsolescent. Nevertheless, I deem it of some importance to give the results obtained in more or less detail, because of their historical value, and because Mr.

Pendleton's residence in India since the paper was written by him has rendered satisfactory changes and deletions practically impossible. Under these circumstances, with the burden of preparing the paper for the press and the reading of the proof falling to me, the author cannot well be held responsible for the inaccuracies and the infelicities of expression which have been carried over from the original manuscript without change. Moreover, the investigation was carried out under my direction, and the plan of attack on the problem, together with the methods employed, were suggested by me. Much that, in the light of present knowledge, is superfluous or patently inexact or erroneous in the paper is due to points of view held by me in 1915, but now happily discarded. For all these, I assume the entire responsibility, and absolve Mr. Pendleton in that regard.

On the other hand, the work having been carried out at my suggestion and under my direction, I feel constrained, in justice to myself, to say that the views expressed in this paper, and the conclusions drawn are wholly Mr Pendleton's and are not in agreement with those held by me. I fail to see the cogency of the arguments set forth for soil classification and mapping at this juncture in soil studies, and cannot admit the pertinence of the analogy between classification of other objects and of soils which the author of this paper employs. My own general conclusion from the results obtained by Mr. Pendleton is that they cast grave doubt on the validity of the Bureau of Soils method of soil classification and mapping, and, incidentally on all methods devised for that purpose to date I cannot see how such methods can serve us in scientific work at all, and, from the practical standpoint, it would surely seem that guides for the purchaser of land could be arranged more cheaply and less elaborately than by the soil mapping methods extant This statement has particular reference to the subdivision of types very minutely, such as, for example, sandy silty clay, clay loam adobe, etc Such minute classification and subdivision in view of the present state of our knowledge of soils, is analogous, in my opinion, to carrying figures out to four decimal places when it is known that the accuracy of the method makes it impossible for them to be correct beyond the first decimal place. In support of this seemingly radical conclusion, the reader will find much of interest in the recent studies of this laboratory on variability in soils, which have already appeared in this same series.

<div style="text-align: right">CHAS. B. LIPMAN.</div>

INTRODUCTION

For several years the University of California has been coöperating with the United States Bureau of Soils in the mapping of the soils of the agricultural portions of the State of California. The system of mapping used is that developed by the Bureau of Soils. During the year 1914–1915 the writer, representing the University of California, was engaged in some of this soil survey work. In that year, in the field, many questions arose regarding the criteria used, the methods,

and the results of the scheme of mapping. It was thought that possibly some of the many questions could be answered through a laboratory study of some typical soils. This paper is a description of certain parts of the work done in this connection.

THE NEED OF A CLASSIFICATION OF SOILS

Since soils consist of a number of more or less distinct groups they are fitting subjects for classification. In fact, it is my belief that it is as necessary to have a classification for soils as for any other group of natural objects in order that "the various and complex relations may be shown as far as practicable,"[1] and that there be a definite basis for systematic and thorough investigations.[2] The advantages of a classification of soils are apparent. But because soils grade gradually into one another, rather than exist as discrete individuals which can be more easily considered and treated from a systematic standpoint, the problem of evolving a satisfactory classification has been particularly difficult. The many and diverse classifications proposed, and the difficulty of applying many of these classifications under conditions other than those for which they were evolved, testify to the difficulty of the task in question.

The mapping of soils without a classification is impossible, and so a brief summary of the development of soil mapping will bear a close relation to the development of soil classification.

HISTORICAL DEVELOPMENT OF THE CLASSIFICATION OF SOILS

The early history of the making of soil maps is that of geologic maps as well, when soils, from the agricultural standpoint, and the less distinct geological formations as such, were not sharply distinguished. Blanck[3] has an excellent treatment of the development of soil mapping and of the modern continental European conceptions of the nature and significance of soil maps. According to Blanck the earliest record of a proposal to make a map to show something of the nature of the actual material composing the surface of the earth is that of Lister's proposal, in 1683, to the Royal Society of London.

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[1] Coffey, G. N., Proc. Amer. Soc. Agron., vol. 1 (1909), p. 175.

[2] Cameron, F. K., Eighth Internat. Cong. Chem., vol. 26 (1912), secs. vɪᴀ–xɪb; app. pp. 699–706.

[3] Fühling, Landw. Ztg., vol. 60 (1911), pp. 121–45.

But it was not until 1743 that Packe executed a map of Kent, showing the occurrence of minerals by symbols. Apparently the next advance was by the Germans, when Füchsel, 1773, and Glöser, 1775, first used colors to show granite, limestone, etc. This work constituted the first real geologic map in the modern sense. There was not much activity in this line of geologic work until 1870 or later. Such activity as there was showed a lack of emphasis on soils in the agricultural sense of the term.

The work on the geologic drifts of northern Europe, and studies of the more recent lowland formations and soils of Germany led to soil mapping. The first real soil map, according to Blanck, was prepared by Benningsten-Förder of Halle, in 1864–67; while Carnot[4] states that in 1863 M. Scipion Gras used superposable maps of the Department of Isère, showing (1) geology, (2) agricultural soils, (3) altitudes of agricultural regions, and (4) culture. The first true geologic-agronomic map published by the Preussischegeologische Landesanstalt appeared in 1878.

The school of soil classification and mapping just mentioned, using the geologic maps and methods as a point of departure have evolved numerous though similar systems of recording the agrogeologic data on the map. The geologic formation is shown by the color, and the soil textures by symbols, while one or more of the following groups of data appear and may be shown: topography by contours, subterranean water by blue figures, location of borings in red with figures referring to tables, amount of plant food elements or substances by figures or hatchings, varying directions, color, or nature of lines, etc. The nature and amount of the data shown and the manner of representing them vary a great deal. Some soilists, to use a term proposed by Coffey,[5] advocate and use superposable maps to show one or more groups of data, thus avoiding unnecessary confusion on the main map.

Hazard[6] proposed a scheme of classification which is quite as directly connected with the economic factors controlling the crops grown, and with the assessable valuation of the land, as with the actual or potential fertility of the soil itself. There are several classifications of this type, involving the assessable values of the land.

[4] Rapport sur les cartes agronomiques, Bull. Min. Agr. France, 1893, no. 8, pp. 956–73.

[5] Jour. Amer. Soc. Agron., vol. 8 (1916), p. 239.

[6] Landw. Jahrb., vol. 29 (1900), pp. 805–911.
Gregoire, A., and Halet, F., Bull. Inst. Chem. et Bact. Gembloux, 1906, no. 75, pp. 1–43.

This development of the mapping of soils as an outgrowth of areal geology in France and Germany may be contrasted with the development of soil classification from other viewpoints, such as that of the Russian school. In Russia there is not the predominance of residual and shallow soils which characterize much of western Europe and which in France especially have led to the adoption of the geologic basis of classification. Dokoutchayev and Sibirtzev have been the chief proponents of a classification of soils based upon the "conception of a soil as a natural body having a definite genesis and a distinct nature of its own."[7]

The genetic conditions of the formation of natural soils include the following variable factors which cause variation:

(1) The petrographic type of the parent rock; (2) the nature and intensity of the processes of disintegration, in connection with the local climatic and topographic conditions; (3) the quantity and quality of that complexity of organisms which participate in the formation of the soil and incorporate their remains in it; (4) the nature of the changes to which these remains are subjected in the soil, under the local climatic conditions and physico-chemical properties of the soil medium; (5) the mechanical displacement of the particles· of the soil, provided this displacement does not destroy the fundamental properties of the soil, its geo-biological character, and does not remove the soil from the parent rock; and (6) the duration of the processes of soil formation.

Upon this genetic basis there has been developed a series of soil zones, ranging from the laterite soils in the tropics to the tundras in the Arctic regions. The outstanding and controlling factor in the scheme proposed is the relation of these zones to climate. For this reason the statement usually seen is that climate is the basis of the classification.[8] There are nearly as many groups of intra-zonal and azonal soils as of those belonging to the zones proper. The former include alkali, marshy, alluvial, and other soils.

Hilgard, while actively interested in the genetic viewpoint of soil classification, was the foremost proponent of a classification upon the basis of the natural vegetation growing upon the soil.[9] This criterion is not always available, though some groups of plants, as the alkali tolerant ones, are almost invariably present where the condi-

[7] Exp. Sta. Record, vol. 12 (1900), p. 704.
See also Sibirtzev, Cong. Geol. Intern., 1897, pp. 73–125; abstract *in* Exp. Sta. Rec., vol. 12 (1900–01), pp. 704–12, 807–18.
Tulaïkoff, N., The Genetic Classification of Soils, Jour. Agr. Sci., vol. 3 (1908), pp. 80–85.
[8] Coffey, U. S. Bur. Soils, Bull. 85 (1912), p. 32; Jour. Amer. Soc. Agron., vol. 8 (1916), p. 241.
[9] Hilgard, E. W., Soils (New York, Macmillan, 1906), pp. 487–549.

tions are unfavorable for the less resistant plants. Later Hilgard and Loughridge[10] claimed that it is impracticable to attempt "a satisfactory tabular classification in which each soil shall at once find its pigeonhole prepared for it . . . because the subject matter is as yet so imperfectly known." However, this does not dispute the justification for making classifications for specific purposes or of specific regions. With respect to this point there seems to be confusion. The question is not whether soils can be classified at all or not, for every observant farmer classifies the soil with which he is familiar, but whether a satisfactory classification is possible over a large territory, where soils are subject to the varying action of the important soil forming agencies.

Still another type of soil mapping is that of Hall and Russell, which is given in their admirable Report on the Agriculture and Soils of Kent, Surrey, and Sussex."[11] In this district the soils are largely residual, and form quite distinct groups, depending upon the parent geologic formation. These groups of soils, such as the Clay-with-flints and the Thanet beds, have very definite agricultural properties; hence the treatment of all phases of agriculture upon each separate group of soils. Hall and Russell[12] present an excellent discussion of the methods of soil classification and the interpretation of the soil analyses used in their study. Russell[13] gives a very similar though briefer treatment.

There are other more or less specialized classifications that have been applied to local conditions and problems. As an example may be cited Dicenty's work on grape soils.[14]

Various modifications of the above schemes of classifying and mapping soils are found in general texts on soils.[15] Nowacki[16] proposes a curious system, *Genera et Species Terrarum.* It is in Latin terminology. The genera are based on the quality of the soil, whether stony, sandy, clayey, peaty, etc., and the species are dependent upon the quantities of organic matter and clay.

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[10] The Classification of Soils, Second Intern. Agrogeol. Conf., Stockholm, 1910, p. 231.

[11] London, Bd. Agr. and Fish., 1911.

[12] Jour. Agr. Science, vol. 4 (1911), pp. 182–223.

[13] Soil Conditions and Plant Growth (London, Longmans, 1913), pp. 132–48.

[14] Die ampelogeologische Kartierung. First Intern. Agrogeol. Cong., Budapest, 1909, pp. 257–71.

[15] Ramann, E., Bodenkunde, Berlin, Springer, 1911.
Mitscherlich, E. A., Bodenkunde, Berlin, Parez, 1905.

[16] Praktische Bodenkunde (Berlin, 1892), pp. 130–80.

Soil Surveying in the United States.—In a brief way, it has been shown how there arose the different systems of soil classification. Only a few typical systems of classifications, and something of the reasons for the divergences, have been mentioned.[17] Probably the one agency that has carried on the most extensive soil classification and mapping is the Bureau of Soils of the United States Department of Agriculture. It is now proposed to discuss and in a measure criticize the work of the Bureau of Soils, the one organization that has, more than any other, succeeded in applying a detailed system of soil classification over extensive areas.

The problems that the Bureau had to face during its early existence were special studies of the soils of certain crops, especially of the tobacco districts.[18] Later the soil utilization work of the Bureau of Soils was transferred to other branches of the Department of Agriculture, leaving as the main task for the Bureau the systematic classification and mapping of the soils of the United States.

Coffey[19] has so well discussed the present day conceptions of the bases for the classification of soils, that it does not seem necessary to repeat any portion of that excellent statement here. He showed that the Bureau of Soils, in its method of classifying soils, uses a combination of a number of systems. This matter is dealt with more in detail in an article by Coffey,[20] and the Report of the Committee on Soil Classification of the American Society of Agronomy.[21] The question often arises as to the validity of making the close distinctions regarding color, texture, geologic origin, etc., and is one which should be dealt with in order to render less empirical the nature of most of the criteria which are used at present. See the Report of the Committee on Soil Classification and Mapping.[22]

Because of different views regarding soils and soil fertility from those held by the Bureau of Soils, the Illinois Agricultural Experiment Station has undertaken a soil survey and classification, under the direction of Dr. C. G. Hopkins, which is independent of the Bureau

[17] See Coffey's excellent treatment of the soil survey work in this country. The Development of Soil Survey Work in the United States with a Brief Reference to Foreign Countries, Proc. Amer. Soc. Agron., vol. 3 (1911), pp. 115–29.

[18] Whitney, Extension and Practical Application of Soil Surveys, Off. Exp. Sta., Bull. 142 (1903), pp. 111–12; The Purpose of a Soil Survey, U. S. Dept. Agr., Yearbook, 1901, pp. 117–32.

[19] A Study of the Soils of the United States, U. S. Bur. Soils, Bull. 85 (1912), pp. 24–38.

[20] Jour. Amer. Soc. Agron., vol. 8 (1916), pp. 239–43.

[21] *Ibid.*, vol. 6 (1914), pp. 284–88.

[22] *Ibid.*, vol. 8 (1916), pp. 387–90.

of Soils, and differs from its methods in a number of ways. Since the soils of Illinois are of a much narrower range of variation than are those of the whole of the United States, the system of classification for the state need not be so elaborate. The soils are divided accordingly as they have been glaciated or not, and if glaciated, in what glaciation period. They are further divided according to color, topography, and texture of soil and subsoil.[23] Correlation of the types of soil mapped in the various areas, one of the greatest sources of criticism of the Bureau of Soils survey methods, is more easily handled in the Illinois work, since it is possible for the one in charge of the work to pass personally, while in the field, upon all correlation and the establishment of all new types. It is insisted that the field men map accurately and in sufficient detail. This insures the accuracy of the maps as regards the standards adopted, the information is specific, and the local users of the maps are not misled.[24] In connection with the field classification and mapping, pot and plot cultures are carried on, not so much to test the relative fertility of the untreated soils, but to determine the effects of the application of various sorts and quantities of fertilizers. Hopkins,[25] to show the differences in detail between the U. S. Bureau of Soils mapping and that of the Illinois Experiment Station, compares a U. S. Bureau survey of 1902 with a state survey published in 1911. This is not entirely fair, because with the increase of field knowledge of soils gained by them and the realization of the need of representing the soils in more detail, a survey made by the Bureau in 1911 would almost certainly show much more detail and show it with greater accuracy than the maps made in the early period of the work. This point may be strengthened by the notes given below on the comparison of a portion of an early survey made in southern California by the Bureau of Soils with a recent survey of the same soils made by the Bureau and the University of California working in coöperation.

PLAN OF THE PRESENT STUDY

The present study is an attempt to see if certain soil types mapped as the same from different areas in the state of California, and judged to be the same by the criteria used by the Bureau of Soils, are the

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[23] Hopkins, Soil Fertility and Permanent Agriculture (Boston, Ginn, 1910), pp. 54–57.

[24] *Ibid.,* p. 115.

[25] *Ibid.,* pp. 114–15.

same or similar when examined from the laboratory standpoint. For example, we may take the Hanford fine sandy loam, which is one of the types that has been used in the present study. According to the criteria of color, mode of formation, origin (as judged by the presence of mica), nature of subsoil, texture, etc., this soil has been found and mapped in a number of areas that have been mapped in this state. But will these various bodies of soil, from widely separated portions of the state, when judged by laboratory and greenhouse studies on samples as nearly representative as possible, appear to be the same or similar?

The types selected for such a study as this should fulfil the following conditions: first, they should have at least a reasonably wide distribution in the state so as to have been mapped in a number of different soil survey areas; and second, the several types should be representative of different classes of soils (clays, loams, sandy loams, etc.), so that contrasts could be obtained between the types.

In the collection of samples it was aimed to obtain representative samples from each of a number of bodies of soil of the types selected; not to obtain possible variations from the ideal in any one body. In the laboratory the soils were compared with regard to their physical composition in the surface horizon, to their chemical composition in three horizons, and to their relative bacteriological activities. In the greenhouse the soils (surface horizon only) were placed in large pots and their comparative ability to produce various crops was studied.

No claim is made that these criteria should be the ones used in determining the systematic classification of soils or in determining the relative fertility of the soils. They were merely used to determine how nearly the soils classed under a given type name agree from the standpoints named.

DISCUSSION OF RESULTS

The bacteriological and chemical determinations were run in duplicate so that the figures presented are averages. It is considered that this gives fairer figures for comparison, especially since the determinations were run on separate samples, and not on aliquots of a single solution from a single sample.

There is a very important factor which should always be kept in mind especially when considering the bacteriological and greenhouse comparisons. This is the factor of the probable error. Though the

advisability of judging all results in the light of the probable error is admitted, no attempt has been made to apply this factor to the results reported in this paper. As the result of the effect which such a factor might have upon the results of bacteriological determinations carried on only in duplicate, or upon the results of greenhouse work done in triplicate, one hesitates to draw conclusions, especially those based upon minor variations. Hence in this work only the more marked results will be considered of significance.

When planning the work it was thought that three or four samples of a type would be enough to show whether or not a given type was approximately uniform, or widely variable, and as to whether the types were similar to one another, or quite dissimilar. But it now seems, after comparing the determinations run on the larger number of samples of the Hanford and San Joaquin types, 9 and 8 respectively, with the determinations run on the Altamont and Diablo types, of which there were a much smaller number of samples, 3 and 4 respectively, that the larger series gives a much better insight into the variations of a given type and affords a much better basis for conclusions.

Hence, as regards the laboratory work thus far carried out, the emphasis has been placed upon the Hanford fine sandy loam and the San Joaquin sandy loam. Determinations have not been completed on the Altamont and Diablo series to the extent that they have on the former two.

It is of no little significance that the Hanford fine sandy loam and the San Joaquin sandy loam are very widely contrasted soils agriculturally. The Hanford is typical of good recent alluvial soil in this state; while the San Joaquin is typical of wide expanses of "old valley filling" soils that are considered poor as regards crop producing power and are underlain by compact iron-cemented hardpan. Consequently, the results of comparing soils so different from an agricultural point of view, and so radically different as regards soil survey criteria (though the textures are quite similar) will be of considerable interest. They are of greater interest than the comparisons between the Diablo and Altamont soils, as the latter are quite similar in agricultural value and use, as well as in field appearances. Between the Diablo or Altamont and the Hanford or San Joaquin one cannot judge as closely regarding variations, for the soils are so radically different. On the other hand, one can compare the soils of the heavy and light types to see to what extent the chemical and bacteriological results differ as compared with the physical results.
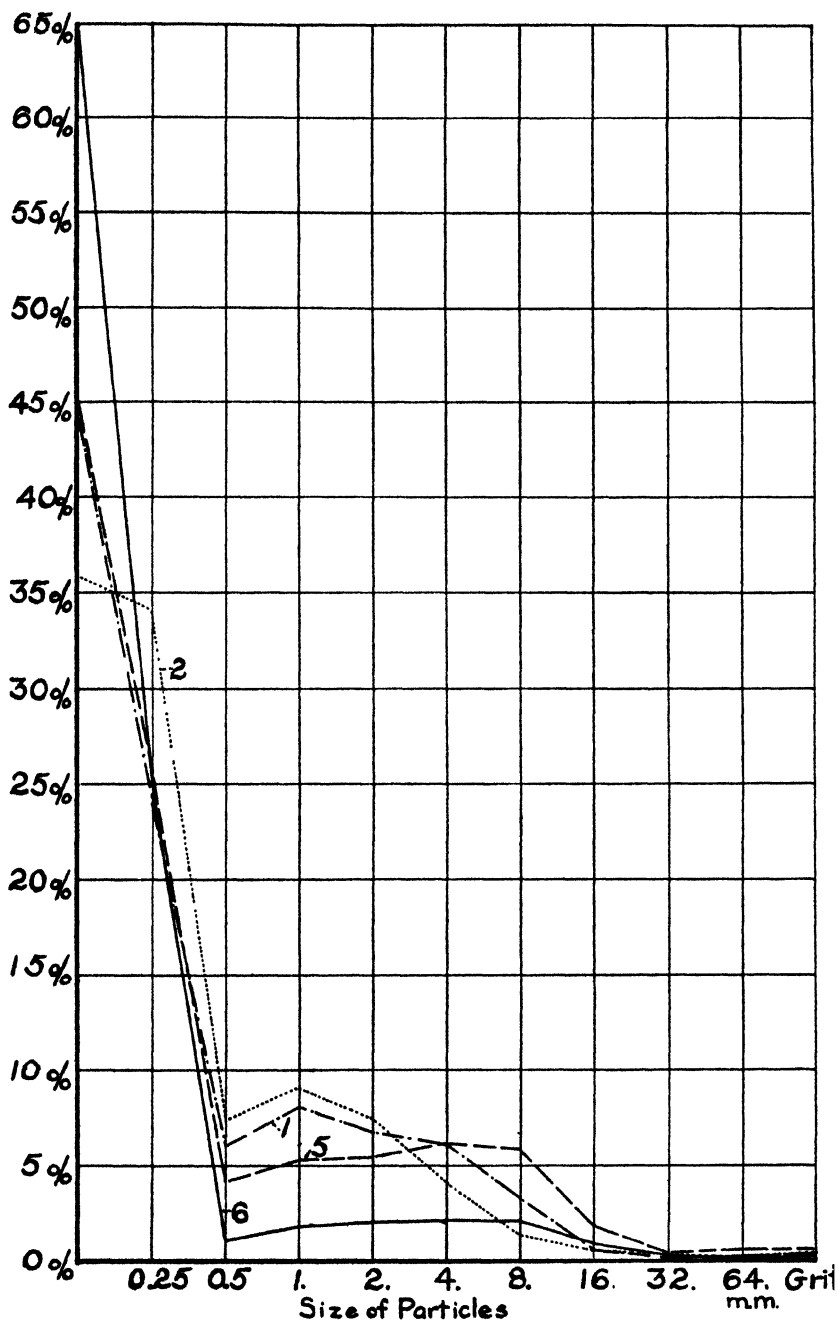
Fig. 1. Graph showing the results of the Hilgard elutriator method of mechanical analysis on the four samples of Diablo clay adobe.

MECHANICAL ANALYSIS

Hilgard Elutriator Method.—That there is a wide variation between the samples is apparent (figs. 1–4). In fact, there is about as wide a range of differences among the samples of the Hanford
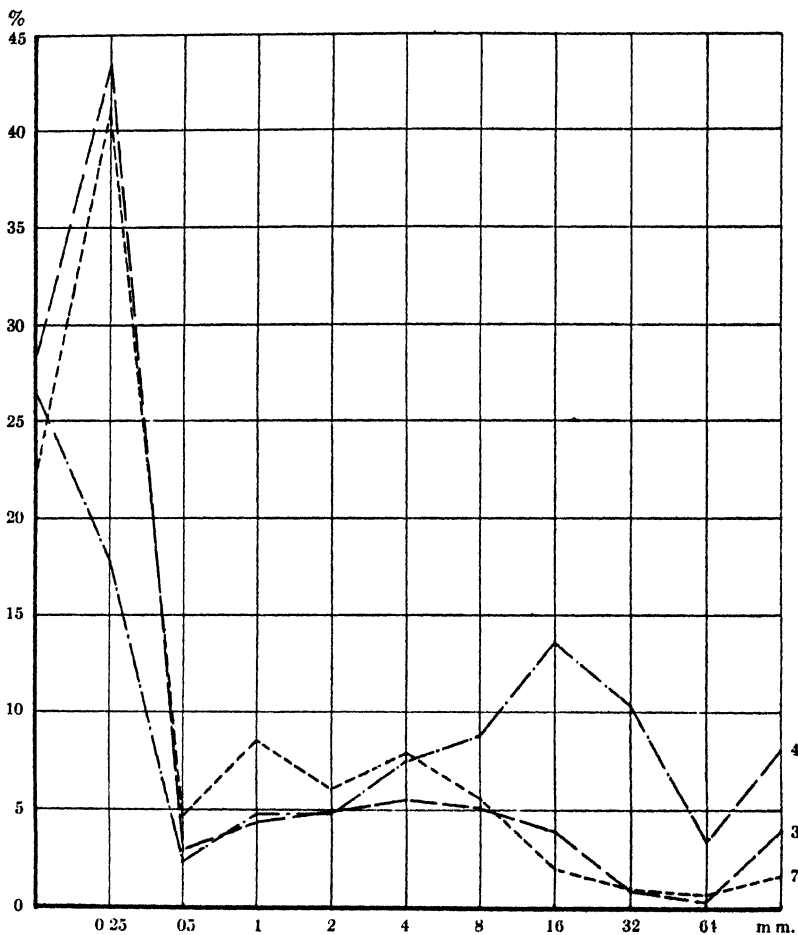
Fig. 2. Graph showing the results of the Hilgard elutriator method of mechanical analysis on the three samples of Altamont clay loam.

fine sandy loam and among those of the San Joaquin sandy loam as between the two types. The most outstanding differences are where they ought to be, to show the differences that the type names presuppose, i.e., in the "coarse sand" (64 mm.) and the "grits." The samples of the San Joaquin sandy loam average a larger proportion of each of these separates than do the Hanford fine sandy loam soils.

In the Hanford, no. 14 is notably heavier than the others, as shown by its silt content, which is nearly half again as great as that of the next highest sample.

The gravel content (sizes above 2 mm.) is interesting in its uniformity. In the San Joaquin soils the two samples above 1% are
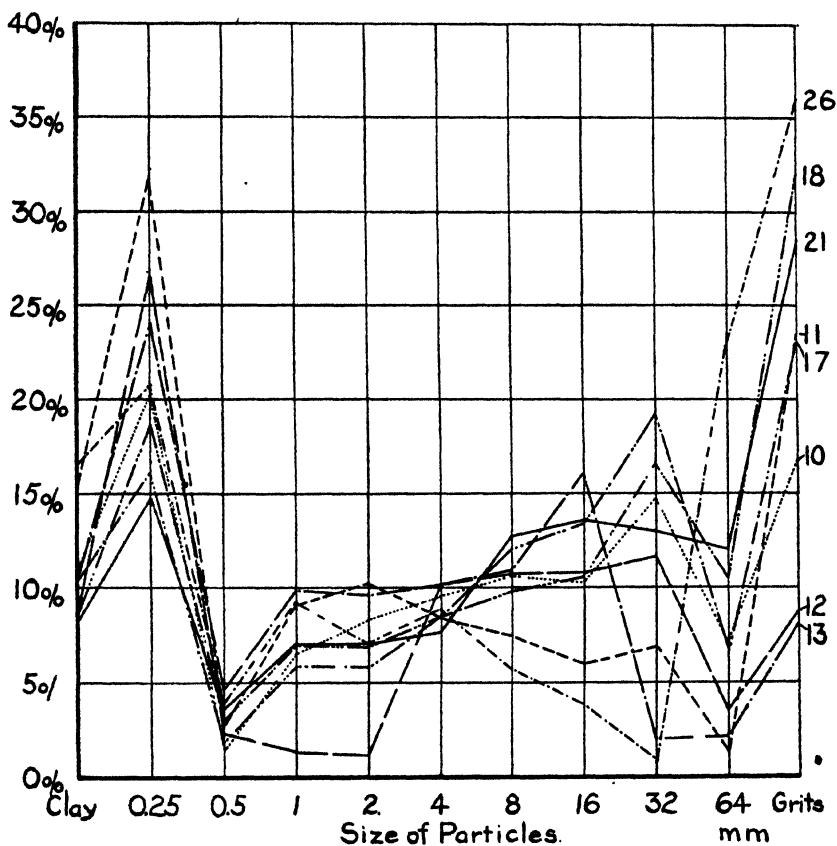
Fig. 3. Graph showing the results of the Hilgard elutriator method of mechanical analysis on the eight samples of San Joaquin sandy loam.

nos. 11 and 26. The material in the latter soil is composed almost wholly of iron concretions, leaving sample no. 11 as the only soil with more than 1% actual gravel. In the Hanford samples none were found to have more than 1.5% gravel.

The Hilgard method does not include any precise subdivision of the soils into groups or classes according to texture. Dr. Hilgard was not in favor of making the fine distinctions in texture that other

investigators have emphasized. But if there were such a scheme, similar to that which the Bureau of Soils uses,[26] it would be an easy matter to compare the results obtained through the use of the elutriator, and determine whether or not the soils examined belong to a given class. The simple comparison of the quantities, in different
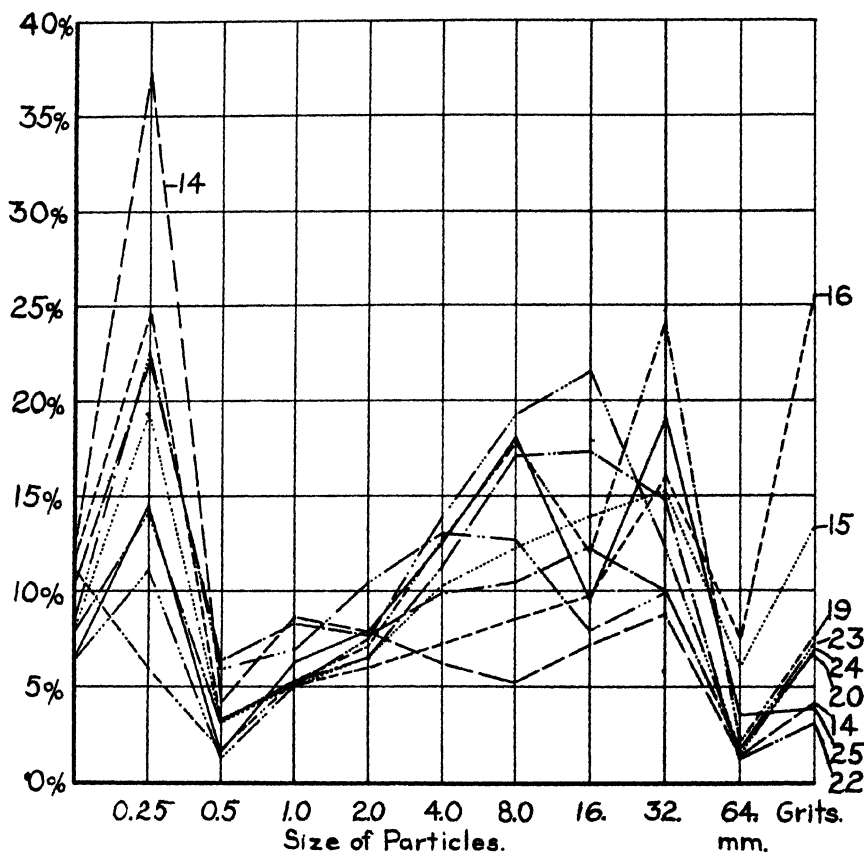
Fig. 4. Graph showing the results of the Hilgard elutriator method of mechanical analysis on the nine samples of Hanford fine sandy loam.

samples, of any given separate or separates is not absolute. For it must be realized that the conception of a soil class includes a certain range in the quantities of particles of the various sizes. This must be so since soils are ordinarily grouped into but ten or twelve class textures, while there exist among soils those with all gradations in the quantities of particles of the various sizes.

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[26] Instructions to Field Parties, U. S. Bur. Soils, Bull. 1914, p. 75; *ibid.*, Bull. 85 (1912), p. 28.

And because the ranges in the sizes of the soil particles separated
by the Bureau of Soils method cut across those of the Hilgard
method, it is impossible to regroup the results so that the Bureau of
Soils grouping into textures may be applied.   But without any such
scheme, desirable as it may be, it has been pointed out that there is
clearly apparent a rather wide variation in the analyses of the several
samples of a type.   All the soils representative of a given type are by
no means closely similar to one another.

<div align="center">TABLE 1—COMPARISON OF TEXTURES</div>

Texture as judged in the field	Texture determined by mechanical analysis
*1 Diablo clay adobe	Clay
2 Diablo clay adobe	Clay
3 Altamont clay loam	*Silty clay
4 Altamont clay loam	Clay loam (sandy)
5 Diablo clay adobe	Clay
6 Diablo clay adobe	Clay
7 Altamont clay loam	Clay loam (heavy)
10 San Joaquin sandy loam	*Fine sandy loam
11 San Joaquin sandy loam	Sandy loam (heavy)
12 San Joaquin sandy loam	*Fine sandy loam
13 San Joaquin sandy loam	*Fine sandy loam (heavy)
14 Hanford fine sandy loam	Fine sandy loam (loam)
15 Hanford fine sandy loam	Fine sandy loam
16 Hanford fine sandy loam	*Sandy loam
17 San Joaquin sandy loam	Sandy loam
18 San Joaquin sandy loam	Sandy loam
19 Hanford fine sandy loam	*Sandy loam (heavy)
20 Hanford fine sandy loam	Fine sandy loam
21 Hanford fine sandy loam	Sandy loam
22 Hanford fine sandy loam	Fine sandy loam
23 Hanford fine sandy loam	Fine sandy loam
24 Hanford fine sandy loam	Fine sandy loam
25 Hanford fine sandy loam	Fine sandy loam
26 San Joaquin sandy loam	Sandy loam

<div align="center">NOTE.—Textures not judged correctly in the field.</div>

Mechanical Analysis by the Bureau of Soils Method.—Among the
other determinations made by the Division of Soil Technology on the
surface horizons of the twenty-four soils used in this investigation
was that of making the mechanical analysis.   The tables show the
percentages of the several separates.   In all cases the figures represent
averages of duplicate determinations and in some cases the averages
of quadruplicate determinations.   With this method, as well as with
the Hilgard elutriator, there are shown wide variations between the
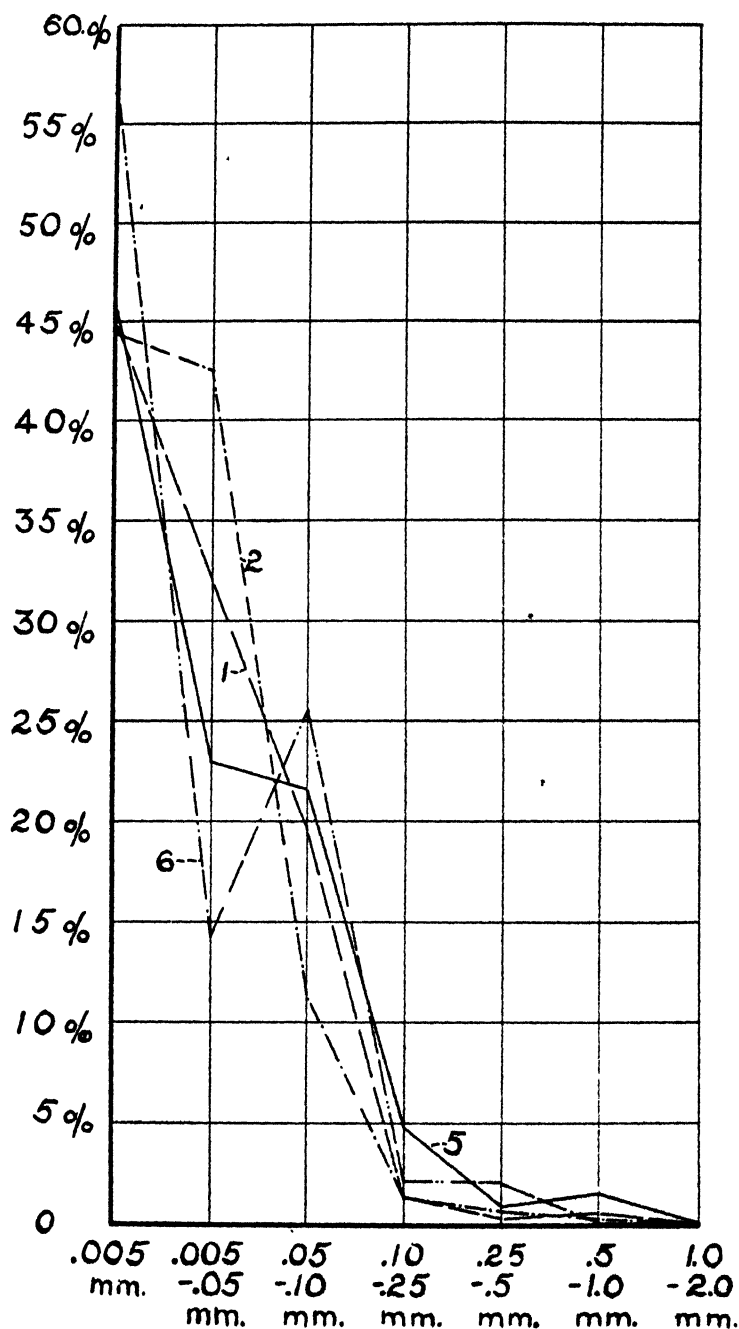
Fig. 5. Graph showing the results of the Bureau of Soils method of mechanical analysis on the four samples of Diablo clay adobe.

samples of a given type. But the graphs of the percentages (figs. 5–8), determined by the Bureau of Soils method for the several types are not as closely similar as the graphs of the elutriator results for the same types. That is, using the Bureau of Soils method, the graph of the Hanford fine sandy loam does not resemble tb&t of the San Joaquin sandy loam as much as do the graphs of the results made
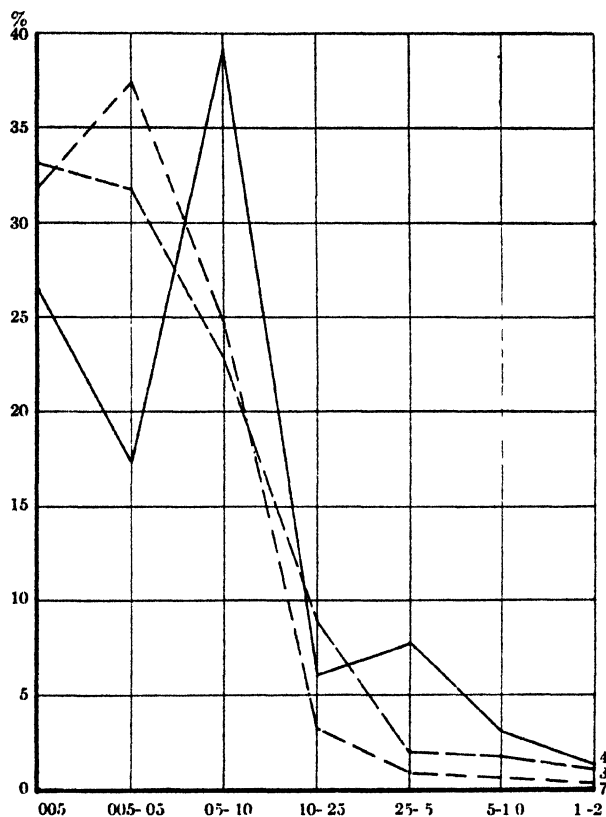
Fig. 6. Graph showing the results of the Bureau of Soils method of mechanical analysis on the three samples of Altamont clay loam.

upon the same soils by the Hilgard elutriator method. This would lead one to believe that the Bureau of Soils method of mechanical analysis is the better suited for separating soils into groups; even though these soils which were classified in the field according to the differences which are the more prominent would be expected to show greater differentiations when examined by the Bureau of Soils laboratory methods.

Comparison of Textures.—Table 1 gives the texture as shown on the soil survey map of the locality, as well as the results of the labora-tory check. This texture as given on the map was also judged by me
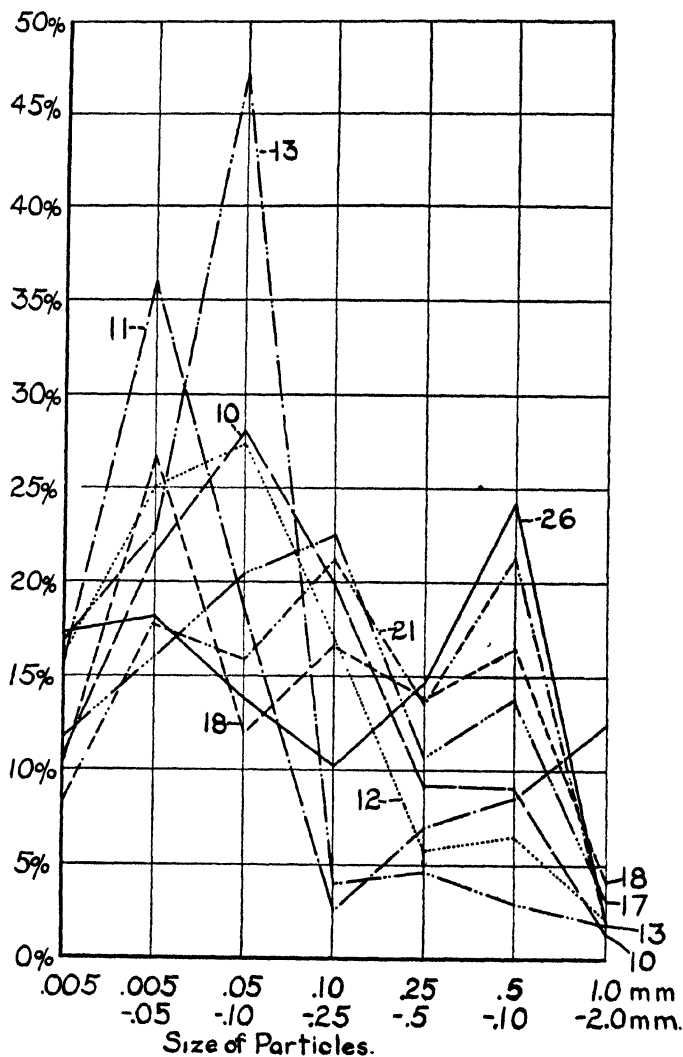
Fig. 7. Graph showing the results of the Bureau of Soils method of mechanical analysis on the eight samples of San Joaquin sandy loam.

in the field to be more or less true to the type as mapped. I say more or less true, for the field notes, as given in appendix B, show that in several cases I was unable to obtain in the locality what I believed to

be a sample of the soil thoroughly typical of the class and type in question. Sample no. 3 had a large lime content which I thought might more or less obscure the texture. "Slightly heavy, and barely enough sand for a sandy loam" is the comment on sample 12, while "a heavy sandy loam, approaching a loam" is found in the notes on sample 13. The second column of the table shows the class subdivisions into which the soils were placed according to the mechanical analysis. The words in parenthesis show modifying conditions but do not indicate a change in the class. In considering the class groups such as sandy loam, fine sandy loam, etc., it should be remembered that though the groups are rather broad, the limits are arbitrary and quite sharp. So the results of a mechanical analysis may place a soil in the sandy loam class if 25% or more is fine gravel, coarse and medium sand, while if less than 25% be present the soil belongs to the fine sandy loam class, providing at the same time the amounts of silt, clay, and fine sand are within the specified limits. The two soils may be a great deal alike in texture though placed in different classes. The failure of my judgment regarding the texture shows one of the difficulties that the field man is continually facing. And his failure to judge textures correctly is one of the causes of criticism of soil survey work.

TABLE 2—MECHANICAL ANALYSES, HILGARD ELUTRIATOR METHOD

Diablo Clay Adobe

| | Separates | | | Samples | | |
Name	Diameter, mm	Velocity, mm per second	1-A %	2-A %	5-A %	6-A %
Clay	.01	0.25	44.16	35.81	44.97	64.63
Fine silt	.01 –.016	0.25	23.91	34.08	25.57	25.13
Medium silt	.016–.025	0.5	5.97	7.37	4.14	1.03
	.025–.036	1	8.10	9.09	5.28	1.83
Coarse silt	.036–.047	2	7.77	7.47	5.45	1.99
	.047–.072	4	6.05	4.09	6.18	2.13
Fine sand	.072–.12	8	3.28	1.33	5.81	2.07
	.12 –.16	16	0.48	0.43	1.73	0.90
Medium sand	.16 –.30	32	0.08	0.21	0.38	0.21
Coarse sand	.30 –.50	64	0.18	0.11	0.49	0.11
Total weight of separates, gm.			19.18	19.62	19.30	19.68
Weight of original sample, gm.			18.83	18.88	18.66	18.16
Grits, % 0.5–2.0 mm.			0.26	0.29	0.57	0.10
Hygroscopic moisture, %			6.20	5.93	7.18	10.12
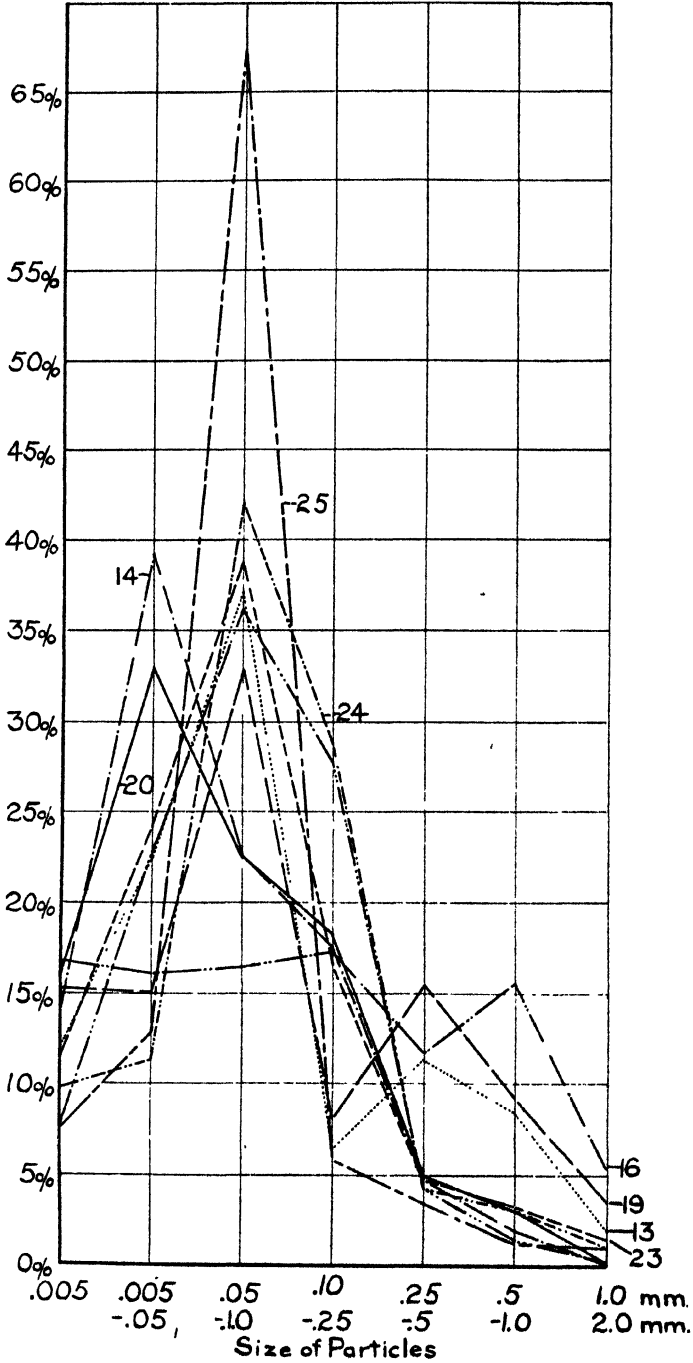
Fig. 8. Graph showing the results of the Bureau of Soils method of mechanical analysis on the nine samples of Hanford fine sandy loam.

TABLE 3—MECHANICAL ANALYSES, HILGARD ELUTRIATOR METHOD

Allamont Clay Loam

	Separates			Samples	
Name	Diameter mm.	Velocity mm. per second	3–A %	4–A %	7–A %
Clay	.01	0.25	28.48	26.41	22.65
Fine silt	.01 –.016	0.25	43.42	17.73	41.18
Medium silt	.016–.025	0.5	2.96	2.39	4.67
	.025–.036	1	4.37	4.82	8.51
Coarse silt	.036–.047	2	4.95	4.89	6.01
	.047–.072	4	5.52	7.52	7.90
Fine sand	.072–.12	8	5.14	8.83	5.54
	.12 –.16	16	3.89	13.61	1.98
Medium sand	.16 –.30	32	0.88	10.40	0.95
Coarse sand	.30 –.50	64	0.21	3.39	0.61
Total weights of separates, gm.			18.71	19.54	20.96
Weight of original sample, gm.			18.50	19.16	19.21
Grits, % 0.5–2.0 mm.			3.98	8.09	1.63
Hygroscopic moisture, %			8.08	4.37	4.09

TABLE 4—MECHANICAL ANALYSES, HILGARD ELUTRIATOR METHOD

San Joaquin Sandy Loam

	Separates					Samples			
Name	Diameter mm	Velocity, mm per second	10–A %	11–A %	12–A %	13–A %	17–A %	18–A %	21–A %	26–A %
Clay	.01	0.25	11.14	15.46	8.99	10.75	10.53	8.72	8.35	16.64
Fine silt	.01 –.016	0.25	20.24	31.88	26.57	24.04	16.20	18 56	14.73	20.78
Medium silt	.016–.025	0.5	1.44	2.73	5.31	4.64	1.81	3.06	3.54	3.83
	.025–.036	1	6.54	9.11	1.33	9.86	5.89	6.93	6.98	9.24
Coarse silt	.036–.047	2	8.36	10.23	1.19	9.59	5.82	6.90	7.10	7.09
	.047–.072	4	9.50	8.41	10.14	10.05	8.46	8.45	7.67	8.89
Fine sand	.072–.12	8	10.66	7.47	10.72	10.92	12.04	9.72	12.86	5.77
	.12 –.16	16	10.30	5 97	10.88	16.14	13.43	10.56	13.53	3.85
Medium sand	.16 –.30	32	14.69	6.91	11.75	1.96	19.21	16.59	13.05	0.86
Coarse sand	.30 –.50	64	7.11	1.32	·3.54	2.12	6.60	10.50	12.14	23.04
Total weight of separates, gm.			20.02	20.44	19.99	20.10	20.38	20.06	20.33	20.14
Weight of original sample, gm.			19.80	19.51	19.72	19.76	19.85	19.86	19.85	19.69
Grits, % 0.5–2.0 mm.			16.70	23.54	8.84	8.10	23.12	32.00	28.50	36.00
Hygroscopic moisture, %			0.98	2.48	1.38	1.22	0.75	0.70	0.75	1.57

NOTE.—All weighings made on the water free basis.

TABLE 5—MECHANICAL ANALYSES, HILGARD ELUTRIATOR METHOD

Hanford Fine Sandy Loam

Separates			Samples								
Name	Diameter mm.	Velocity, mm. per second	14–A %	15–A %	16–A %	19–A %	20–A %	22–A %	23–A %	24–A %	25·A %
Clay	.01	0.25	12.89	8.16	11.97	11.09	10.55	7.97	8.68	6.47	6.65
Fine silt	.01 –.016	0.25	37.25	19.39	24.61	5.95	22.09	14.15	22.57	11.11	14.54
Medium silt	.016–.025	0.5	4.19	3.05	3.22	1.67	6.40	3.15	5.90	1.20	1.59
	.025–.036	1	8.63	5.04	5.06	5.27	8.40	5.29	6.89	5.08	6.36
Coarse silt	.036–.047	2	7.95	6.57	5.99	7.14	7.68	6.47	10.53	7.48	7.91
	.047–.072	4	6.23	10.23	7.27	12.76	9.93	11.30	13.03	13.91	12.64
Fine sand	.072–.12	8	5.26	12.31	8.57	17.79	10.48	17.15	12.71	19.27	18.11
	.12 –.16	16	7.15	13.93	9.76	12.00	12.29	17.39	7.94	21.56	9.55
Medium sand	.16– .30	32	8.81	15.29	16.05	24.20	10.03	14.87	9.88	12.36	19.15
Coarse sand	.30– .50	64	1.43	6.02	7.51	2.13	2.70	2.27	1.85	1.50	3.50
Total weight of separates, gm.			20.19	20.23	20.53	20.08	20.27	20.06	20.30	20.26	19.18
Weight of original sample, gm.			19.46	19.90	19.69	19.82	19.73	19.81	19.78	19.83	19.78
Grits, %	0.5–2.0		4.12	13.23	25.47	7.85	6.71	3.07	7.24	6.85	3.83
Hygroscopic moisture, %			2.73	0.49	1.54	0.89	1.34	0.94	1.10	0.84	1.10

TABLE 6—MECHANICAL ANALYSES, BUREAU OF SOILS METHOD

Diablo Clay Adobe

Separates		Samples			
Name	Diameter mm.	1–A %	2–A %	5–A %	6–A %
Clay	.005	44.81	44.44	45.67	56.01
Silt	.005– .05	32.00	42.51	23.01	14.28
Very fine sand	.05 – .10	19.61	11.35	21.58	25.58
Fine sand	.10 – .25	1.36	1.33	4.81	2.10
Medium sand	.25 – .5	0.26	0.69	0.95	2.05
Coarse sand	.5 –1.0	0.58	0.20	1.56	0.00
Fine gravel	1.0 –2.0	0.03	0.02	0.04	0.00

NOTE.—Determinations made by the Division of Soil Technology.

TABLE 7—MECHANICAL ANALYSES, BUREAU OF SOILS METHOD

Altamont Clay Loam

Separates		Samples		
Name	Diameter mm.	3–A %	4–A %	7–A %
Clay	.005	33.19	26.50	31.84
Silt	.005– .05	31.76	17.35	37.40
Very fine sand	.05 – .10	22.81	39.15	24.70
Fine sand	.10 – .25	8.97	6.08	3.27
Medium sand	.25 – .5	1.99	7.78	0.92
Coarse sand	.5 –1.0	1.74	3.06	0.55
Fine gravel	1.0 –2.0	1.01	1.22	0.22

NOTE.—Determinations made by the Division of Soil Technology.

TABLE 8—MECHANICAL ANALYSES, BUREAU OF SOILS METHOD

San Joaquin Sandy Loam

Separates		Samples							
Name	Diameter mm.	10–A %	11–A %	12–A %	13–A %	17–A %	18–A %	21–A %	26–A %
Clay	.005	10.78	15.77	16.16	16.94	11.77	10.49	8.28	17.38
Silt	.005– .05	21.60	35.97	25.04	22.70	15.97	26.74	17.70	18.17
Very fine sand	.05 – .10	28.07	18.53	27.42	47.01	20.42	12.02	15.92	13.84
Fine sand	.10 – .25	19.96	2.66	17.07	3.99	22.57	16.61	21.27	10.26
Medium sand	.25 – .5	9.20	6.96	5.80	4.69	10.75	13.85	13.57	14.72
Coarse sand	.5 –1.0	9.08	8.51	6.52	2.96	13.81	16.52	21.41	24.26
Fine gravel	1.0 –2.0	1.34	12.52	2.15	1.81	3.13	4.07	2.07	2.02

NOTE.—Determinations made by the Division of Soil Technology.

TABLE 9—MECHANICAL ANALYSES, BUREAU OF SOILS METHOD

Hanford Fine Sandy Loam

Separates		Samples							
Name	Diameter mm.	14–A %	15–A %	16–A %	19–A %	20–A %	22–A %	23–A %	24–A %	25-A %
Clay	.005	14.10	12.08	16.84	15.28	15.95	7.79	10.61	9.83	7.60
Silt ·	.005– .05	39.25	22.42	16.16	15.03	32.90	22.70	24.38	11.42	12.90
Very fine sand	.05 – .10	22.66	37.12	16.46	32.87	22.58	36.15	38.73	42.05	67.37
Fine sand	.10 – .25	17.54	6.51	17.32	8.13	18.20	27.78	16.51	28.73	5.88
Medium sand	.25 – .5	4.71	11.40	11.70	15.42	4.97	4.21	4.66	4.27	3.47
Coarse sand	.5 –1.0	1.99	8.49	15.54	9.27	3.07	1.47	3.28	3.01	.1.27
Fine gravel	1.0 –2.0	0.13	1.91	5.27	3.63	0.20	0.20	1.48	1.02	1.02

NOTE.—Determinations made by the Division of Soil Technology.

Moisture Equivalent.—The moisture equivalents of the surface horizon samples were determined by the Division of Soil Technology (table 10, and figs. 9, 10). The different types gave quite distinct averages, though there was considerable variation within the type. The Diablo clay adobe varied from 37% to 57%, with an average of 47%. The Altamont clay loam varied from 22% to 37%, with 28% as an average. The San Joaquin sandy loam varied from 7% to 15%, with the average of 11%. The Hanford fine sandy loam varied from 11% to 25%, with 15% as the average. These figures show that as a whole the moisture equivalents of the several types are distinct, though there is the usual overlapping in some cases. The samples of a given type are in many instances closely similar, though not always or even usually so.
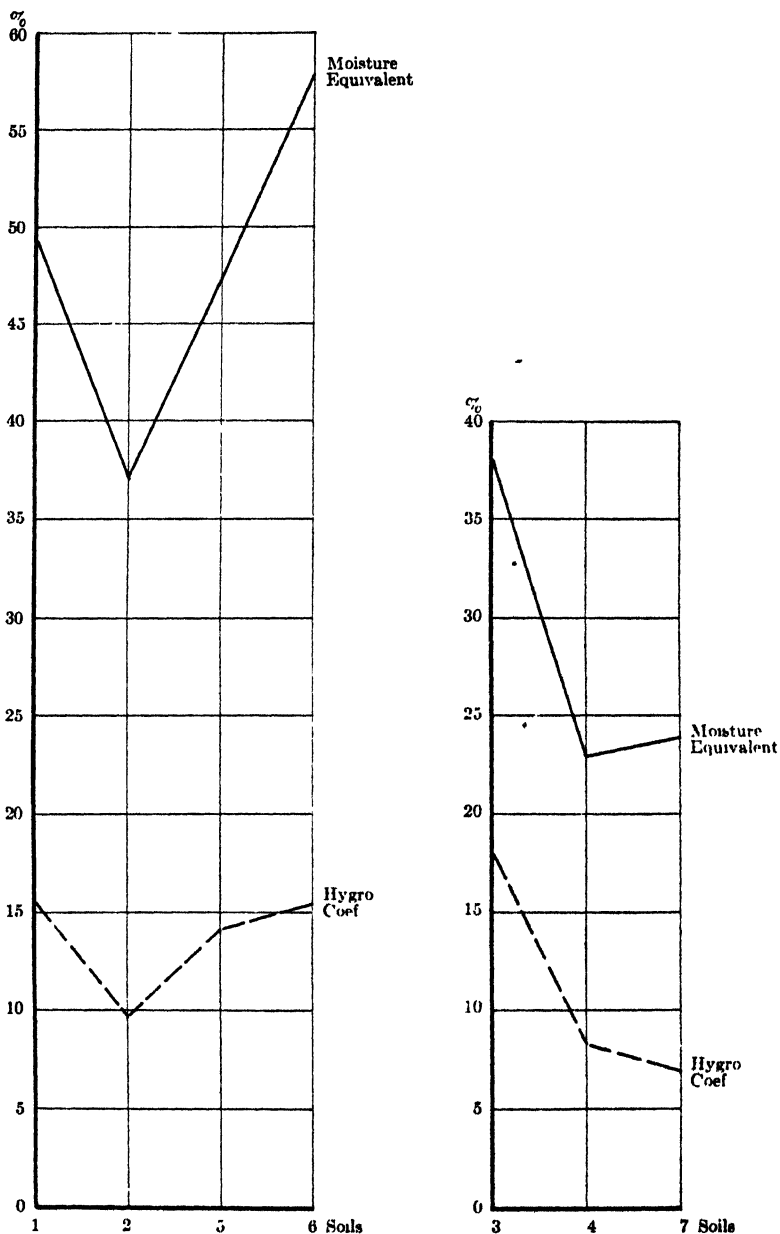
Fig. 9. Graph showing the results of the determination of the moisture equivalent and of the hygroscopic coefficient on the four samples of Diablo clay adobe and the three samples of Altamont clay loam.

TABLE 10—MOISTURE EQUIVALENT

Diablo Clay Adobe			Altamont Clay Loam			San Joaquin Sandy Loam			Hanford Fine Sandy Loam		
No.	%	Average %	No.	%	Average %	No.	%	Average %	No.	%	Average %
1-A	49.70		3-A	38.10		10-A	10.30		14-A	25.80	
	48.90	49.30		37.80	37.95		10.10	10.20		25.20	25.50
2-A	37.40		4-A	23.41		11-A	15.52		15-A	11.50	
	36.80	37.10		22.35	22.88		15.54	15.53		11.20	11.35
5-A	46.55		7-A	23.90		12-A	13.72		16-A	15.60	
	48.10	47.32		23.90	23.90		13.62	13.67		15.60	15.60
6-A	58.80			Average	28.94	13-A	14.50		19-A	13.30	
	56.80	57.80					14.60	14.55		14.30	13.80
	Average	47.88				17-A	8.90		20-A	18.41	
							8.98	8.94		18.38	18.39
						18-A	7.92		22-A	12.73	
							7.87	7.89		12.22	12.47
						21-A	7.16		23-A	11.08	
							7.09	7.12		10.90	10.99
						26-A	11.30		24-A	16.30	
							11.81	11.55		16.17	16.23
							Average	11.18	25-A	11.17	
										12.72	11.94
										Average	15.14

NOTE —Determinations made by the Division of Soil Technology.

TABLE 11—HYGROSCOPIC COEFFICIENT

Diablo Clay Adobe			Altamont Clay Loam			San Joaquin Sandy Loam			Hanford Fine Sandy Loam		
No.	%	Average %	No.	%	Average %	No	%	Average %	No	%	Average %
1-A	15.88		3-A	17.48		14-A	5.35		10-A	2.46	
	15.08	15.48		18.43	17.93		4.70	5.03		2.51	2.49
2-A	9.90		4-A	9.60		15-A	1.31		11-A	3.44	
	9.48	9.69		7.00	8.30		1.39	1.35		3.45	3.44
5-A	14.18		7-A	7.92		16-A	3.90		12-A	3.58	
	13.90	14.04		5.92	6.92		3.60	3.75		3.45	3.52
6-A	15.20			Average	11.05	19-A	1.86		13-A	2.50	
	15.70	15.45					1.80	1.73		2.60	2.55
	Average	13.66				20-A	2.90		17-A	1.84	
							3.02	2.96		1.62	1.73
						22-A	2.48		18-A	2.10	
							2.89	2.69		2.00	2.05
						23-A	2.38		21-A	1.98	
							2.53	2.46		1.92	1.95
						24-A	2.39		26-A	3.57	
						24-A	2.39			3.52	3.53
							2.37	2.38		Average	2.66
						25-A	1.78				
							1.84	1.81			

NOTE.—Determinations made by the Division of Soil Technology.
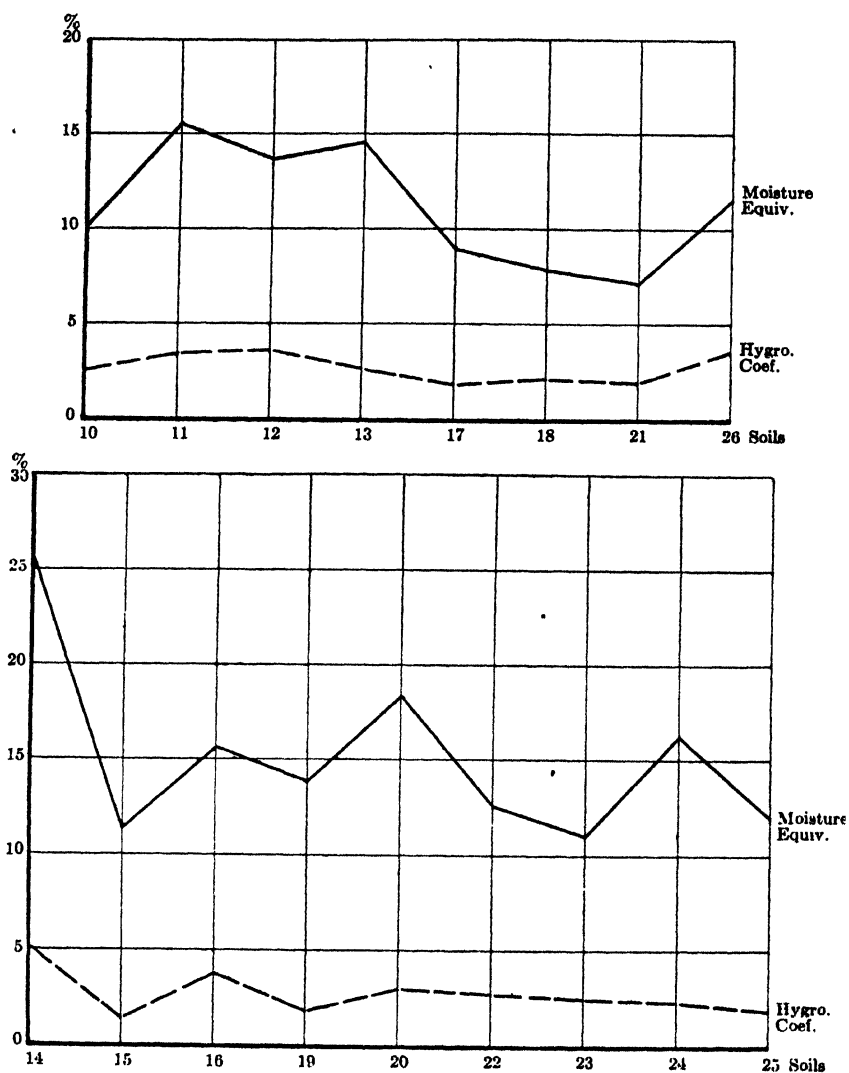
Fig. 10. Graph showing the results of the determination of the moisture equivalent and of the hygroscopic coefficient on the eight samples of San Joaquin sandy loam and the nine samples of Hanford fine sandy loam.

Hygroscopic Coefficient.—The determination of this coefficient, also by the Division of Soil Technology, shows no very distinct values for the several types under consideration (table 11, figs. 9,10). The Diablo clay adobe samples vary from 9.6% to 15.4%, with the average of 13.6%. The Altamont clay loam samples vary from 6.9% to 17.9%, averaging 11%. The San Joaquin sandy loam varies from

1.7% to 3.5%, with the average of 2.66%, while the Hanford fine sandy loam varies from 1.3% to 5%, with the average of 2.68%. There is no question that here the range of values within every type is greater than that from type to type. Even excluding those samples shown by the mechanical analysis to be not true to name there is a wide range within each type—a range too wide to allow one to answer the question of this paper in the affirmative.
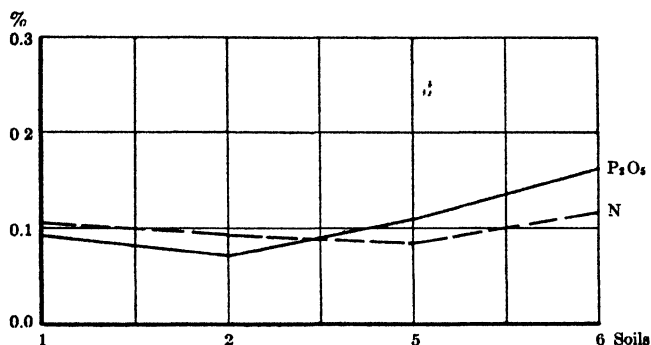
Fig. 11. Graph showing the percentages of nitrogen and of phosphorus in the four samples of Diablo clay adobe.

THE CHEMICAL DATA

TOTAL NITROGEN

Diablo clay adobe.—There is more variation in nitrogen content between the different representatives of the type than one would expect from a visual examination of the soils (table 12 and fig. 11). No. 2 would be expected to contain less nitrogen than no. 5 because of the lighter color, but such is not the case. In the A horizon, no. 5 shows the lowest notal nitrogen content with 0.084%, no. 2 is higher with 0.092%, no. 1 with 0.104%, and no. 6 is the highest with 0.117%. The decrease in the nitrogen content with the increase in depth is normal. In the C horizon, no. 1 has the lowest total nitrogen content with 0.057%, and no. 6 the highest, with 0.078%.

Altamont clay loam.—The agreement between the A samples is fairly close (table 13, and fig. 12). No. 4 has 0.103%, no. 7, 0.104%, and no. 3 has 0.123%. This gives an average for the surface soil of 0.110%, as compared with 0.099% in the Diablo clay adobe. It is to be noted that the nitrogen content of the subsoil is relatively less than that in the Diablo subsoils, 0.071% and 0.056% in the Altamont B and C horizons, respectively, as against 0.076% and 0.065% in the

B and C horizons of the Diablo. The average amount of nitrogen is higher in the A horizon of the Altamont than in the Diablo, contrary to what one would expect from the color of the soils, since the Altamont is typically a brown soil and the Diablo a dark gray to black soil.

San Joaquin sandy loam.—The nitrogen content of these soils is uniformly low (table 14 and fig. 13). from 0.03% to 0.05%, and is but a third to a half of what Hilgard believed adequate for crop production.
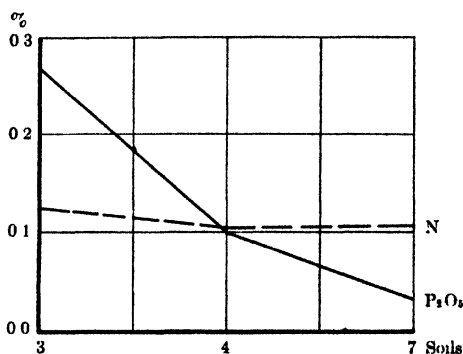
Fig. 12. Graph showing the percentages of nitrogen and of phosphorus in the three samples of Altamont clay loam.
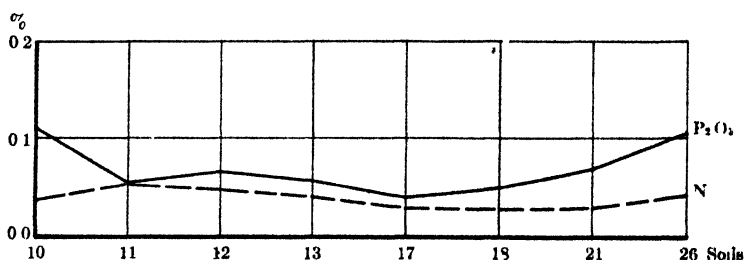
Fig. 13. Graph showing the percentages of nitrogen and of phosphorus in the eight samples of San Joaquin sandy loam.

The nitrogen content is seen to vary more or less directly with the amount of the finer sediments present in the soil—nos. 11 and 12 being heavy members of the type, with 0.05% and 0.047% respectively, and nos. 17 and 18 light members of the type with 0.029% and 0.027% respectively. It may be noted that the nitrogen content of the various horizons are not as far apart as in the other types. The averages for the three horizons are: A—0.037%, B—0.027%, and C—0.026%. It must be borne in mind that the San Joaquin sandy loam horizons are not full 12-inch samples, and that the total depth of the sampling is less.

Hanford fine sandy loam.—Here again in the A horizon the nitro-
gen content is fairly uniform (table 15, and fig. 14), with from 0.045%
to 0.072%, if the extra typical no. 14, with 0.119%, be left out of
consideration. One would suppose these soils to be higher in their
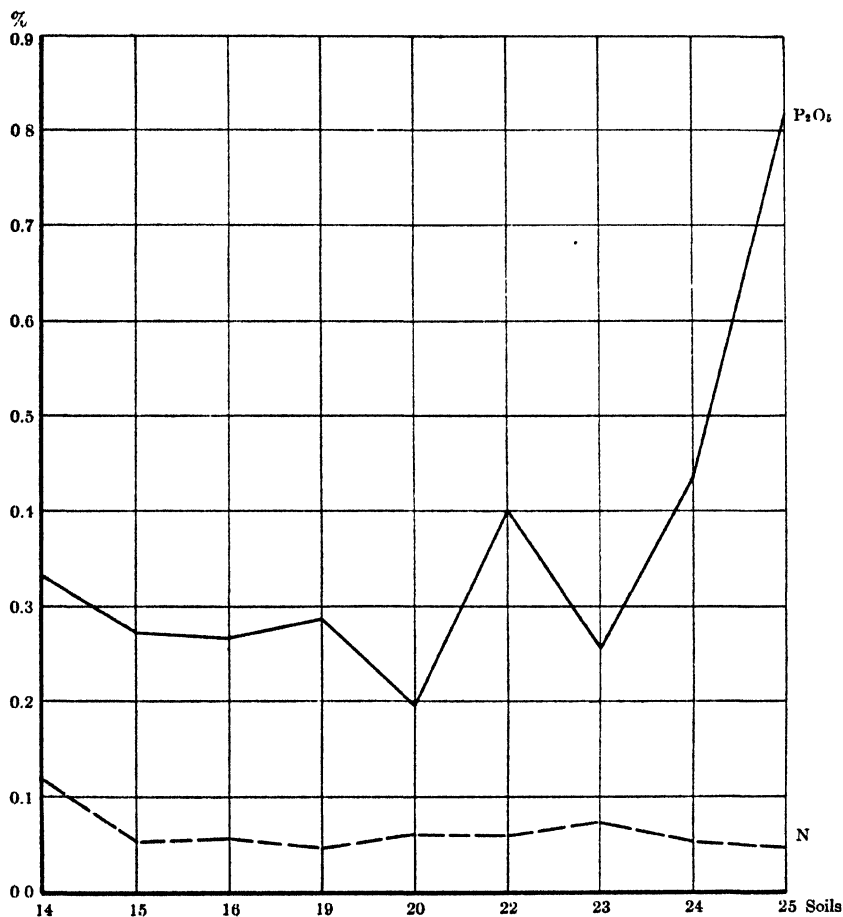
Fig. 14. Graph showing the percentages of nitrogen and of phosphorus in
the nine samples of Hanford fine sandy loam.

nitrogen content, as compared with the San Joaquin series, than the
results show. The B and C horizons of the Hanford samples contain
0.038% and 0.028% nitrogen, respectively, showing that with the
increase of depth there is a more rapid decrease of nitrogen than in
the San Joaquin samples, with the nitrogen content of the C horizon
of the Hanford only 0.002% above that of the C horizon of the San

Joaquin. The greenhouse pot cultures showed the effect of the much higher nitrogen content in no. 14 in giving better color and growth to the plants and especially to the grains. The increase of the nitrogen in the surface of no. 23, as compared with the B and C horizons, might be ascribed to the fertilizers applied to the orange grove where this sample was collected; yet no. 24 is a truck soil which has been fertilized to a considerable extent with barnyard manure. The nitrogen content of this type, as judged by the previous standards, is quite inadequate.

Compare the nitrogen content of the A horizons of the four types: The Diablo has an average of 0.099%, with a range or from 0.084% to 0.117%; the Altamont has an average of 0.110%, with a range of from 0.103% to 0.123%; the San Joaquin has an average of 0.037%, with a range of from 0.027% to 0.050%; and the Hanford has an average of 0.062%, with a range of from 0.045% to 0.119%. Thus the total nitrogen content of the several types is reasonably constant within the type and rather distinct for the types.

TABLE 12—TOTAL NITROGEN

Diablo Clay Adobe

	Horizon					
Sample	A %	Average %	B %	Average %	C %	Average %
	0.109	0.105	0.076	0.069	0.056	0.057
1	0.101		0.063		0.059	
2	0.100		0.072		0.062	
	0.084	0.092	0.064	0.068	0.058	0.060
5	0.085		0.065		No sample	
	0.084	0.084	0.065	0.065		
6	0.114		0.097		0.075	
	0.122	0.118	0.107	0.102	0.083	0.079
Average		0.100		0.076		0.065

TABLE 13—TOTAL NITROGEN

Altamont Clay Loam

	Horizon					
Sample	A %	Average %	B %	Average %	C %	Average %
3	0.123		0.089		0.069	
	0.124	0.123	0.087	0.088	0.067	0.068
4	0.103		0.054		0.041	0.041
	0.103	0.103	0.053	0.053	0.041	0.041
7	0.106		0.070		0.061	
	0.104	0.105	0.077	0.073	0.059	0.060
Average		0.110		0.071		0.056

TABLE 14—TOTAL NITROGEN

San Joaquin Sandy Loam

Sample	Horizon A %	Average %	B %	Average %	C %	Average %
10	0.037		0.026		0.022	
	0.038	0.037	0.029	0.027	0.020	0.021
11	0.051		0.042		0.038	
	0.051	0.051	0.046	0.044	0.040	0.039
12	0.049		0.032		0.042	
	0.045	0.047	0.034	0.033	0.040	0.041
13	0.040		0.038		0.033	
	0.040	0.040	0.043	0.040	0.033	0.033
17	0.028		0.019		No sample	
	0.030	0.029	0.018	0.018		
18	0.028		0.016		0.018	
	....	0.028	0.017	0.016	0.021	0.019
21	0.029		0.012		0.014	
	0.030	0.029	0.012	0.012	0.014	0.014
26	0.041		0.026		0.016	
	0.041	0.041	0.027	0.026	0.017	0.016
Average		0.038		0.027		0.026

TABLE 15—TOTAL NITROGEN

Hanford Fine Sandy Loam

Sample	Horizon A %	Average %	B %	Average %	C %	Average %
14	0.113		0.084		0.060	
	0.126	0.119	0.081	0.082	0.057	0.058
15	0.052		0.039		0.028	
	0.055	0.053	0.043	0.041	0.027	0.028
16	0.058		0.030		0.020	
	0.054	0.056	....	0.030	0.023	0.021
19	0.046		0.025		0.024	0.023
	0.044	0.045	0.025	0.025	0.023	0.023
20	0.062		0.032		0.024	
	0.058	0.060	0.034	0.033	0.02ᴸ	0.023
22	0.057		0.033		0.025	
	0.061	0.059	0.036	0.034	0.023	0.024
23	0.075		0.028		0.020	
	0.071	0.073	0.030	0.029	0.016	0.018
24	0.050		0.032	0.034	0.028	0.028
25	0.045		0.031		0.022	
	0.047	0.046	0.032	0.031	0.024	0.023
Average		0.062		0.038		0.027

HUMUS

Diablo clay adobe.—The variations in the humus content of the A samples (table 16, and fig. 15) are moderate, 1.1% to 1.4%, while the B and C horizons do not agree so closely with each other or with the
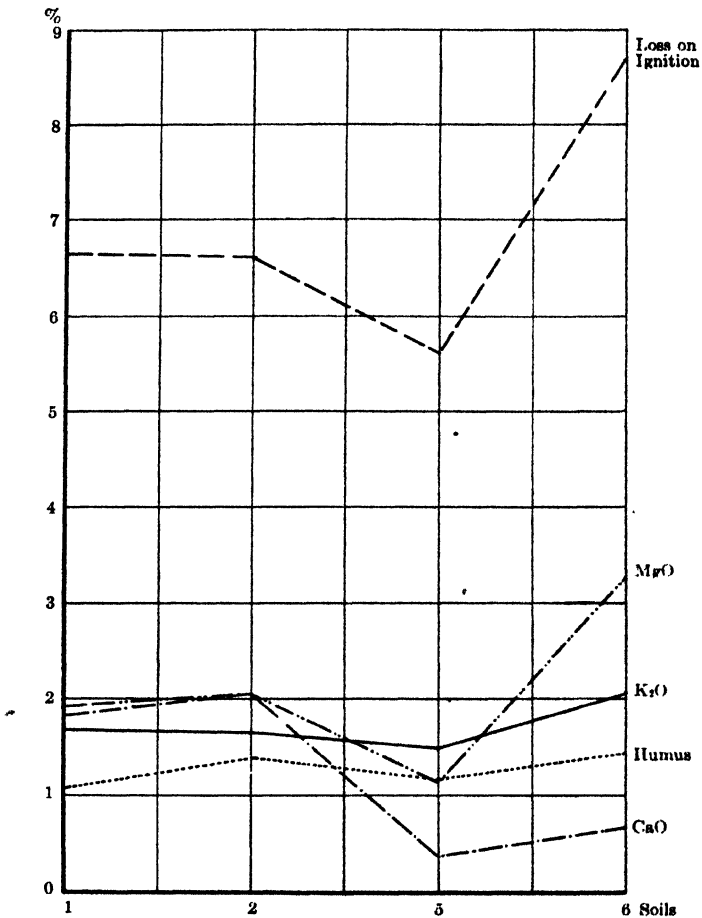
Fig. 15. Graph showing the loss on ignition, the amount of humus, and the percentages of calcium, magnesium, and potassium in the four samples of Diablo clay adobe.

surface foot. The average content of humus in the A samples is 1.26%, in the B samples 0.95%, and in the C samples 0.75%. It is worthy of note that soil no. 2, with the lightest color of the four, and what might be supposed to be a lower humus content, has next to the highest amount.

Altamont clay loam.—Here the variations in the humus content (table 17, and fig. 16) are small in the A horizon, 1.1% to 1.3%. The average is 1.24%. The B and C samples show a good parallelism among themselves, but not so good when compared with the surface. The average of the B horizon is 0.84%, and of the C horizon 0.57%.
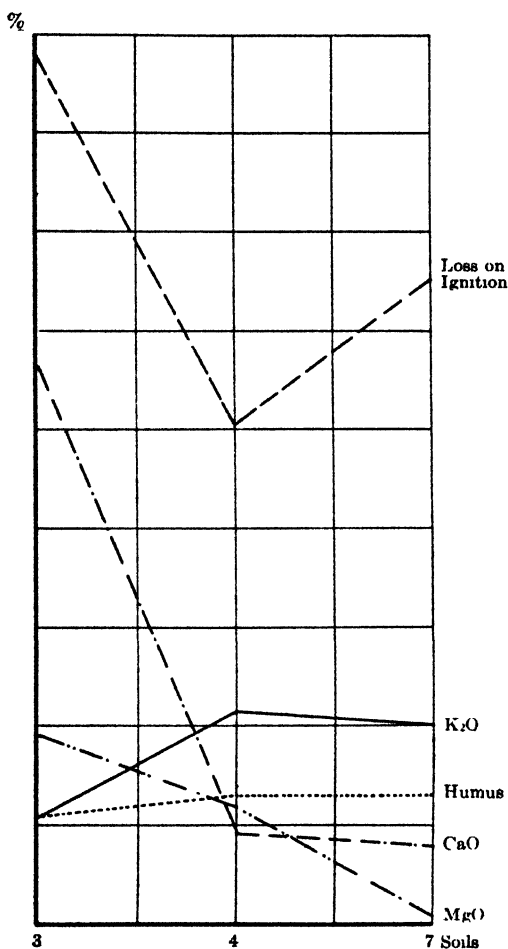
Fig. 16. Graph showing the loss on ignition, the amount of humus, and the percentages of calcium, magnesium, and potassium in the three samples of Altamont clay loam.

San Joaquin sandy loam.—This type contains a considerable quantity of humus (table 18, and fig. 17) when one takes into consideration the popular criteria for the presence of humus, for the red to reddish brown San Joaquin soils are very different from the brown Altamont or the black Diablo soils. The samples of this type gave

light colored or nearly colorless humus solutions. But when the aliquots were ignited, after evaporation, there was a very noticeable blackening and charring of the residue, together with a considerable
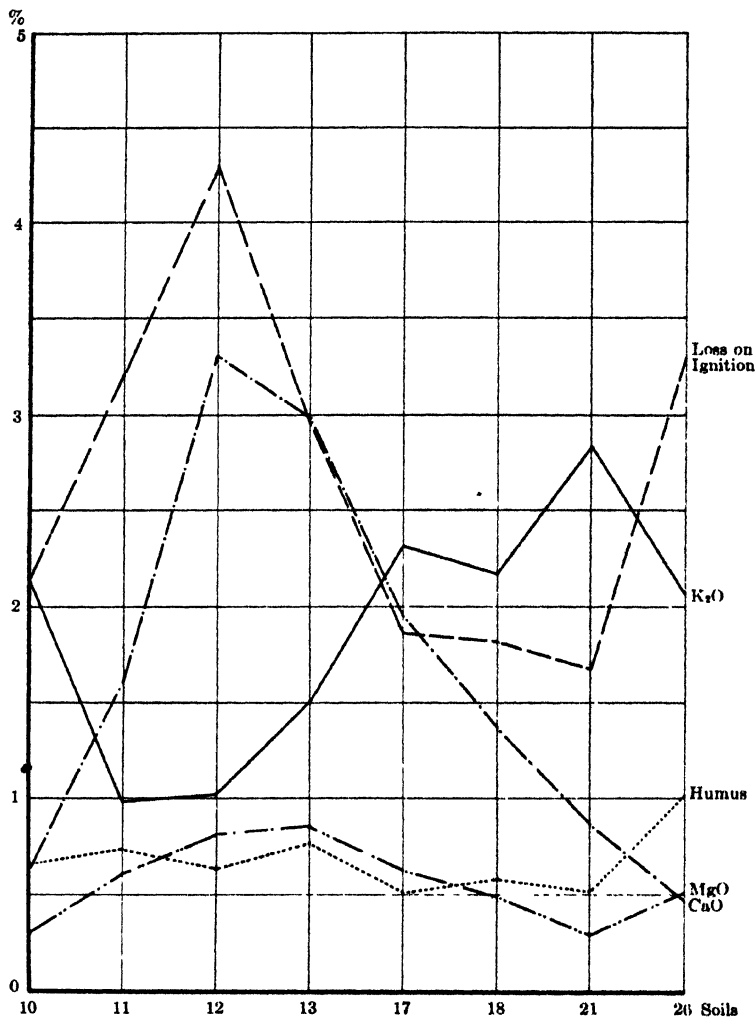
Fig. 17. Graph showing the loss on ignition, the amount of humus, and the percentages of calcium, magnesium, and potassium in the nine samples of San Joaquin sandy loam.

loss in weight. This phenomenon, in the light of the work of Gortner,[27] shows that these soils have a "humus" content above that which they might be supposed to have, because of the almost complete absence of

[27] Soil Science, vol. 2 (1916), pp. 395-442.

the "black pigment." Soil no. 26, probably the only virgin soil in the series, shows a particularly high content of humus for such a soil, though from the color of the soil one would suspect but very little humus. The agreement between the three horizons of the San Joaquin sandy loam samples is close. The average content of humus was 0.68% in the A, 0.51% in the B, and 0.38% in the C horizon.

Hanford fine sandy loam.—The variations in humus content in this type are greater than in any of the others (table 19, and fig. 18). This is possibly because of two factors: the open texture of the soil, hence the rapid loss of organic matter by oxidation processes; and secondly, the high agricultural value of this soil, which has led to a greater application of fertilizers than has been the case with the other soils. The actual variations in the humus content are large, 0.7% to 2.1% with the average of 1.15% for horizon A, from 0.5% to 1.8% with the average of 0.81% for B, and from 0.44% to 1.07% with the average of 0.59% for C. The extra-typical sample no. 14 is above any of the others in the total humus content. The variations in the subsoil humus content are more or less parallel to those of the surface soil.

The following averages of the humus content of horizon A, Diablo 1.26%, Altamont 1.24%, San Joaquin 0.68%, Hanford 1.15%, show that there is not much difference between the soils, except for the San Joaquin sandy loam, which has an average of half the others. Within the type the soils may be nearly alike, as in the San Joaquin and Altamont, or may be variable to a large degree, as in the Hanford. The variations in the humus content of the soils are small, considering the diverse nature of the soils, and the usual methods for judging the quantity of humus.

TABLE 16—HUMUS (AND HUMUS ASH)

Diablo Clay Adobe

| | Humus Horizons | | | | | | Humus ash Horizons | | | | | |
Sample	A %	Average %	B %	Average %	C %	Average %	A %	Average %	B %	Aerage %	C %	Average %
1	1.08		0.51		0.18		0.55		0.75		0.45	
	1.08	1.08	0.51	0.51	0.24	0.21	0.56	0.56	0.73	0.74	0.46	0.46
2	1.40		1.16		1.09		1.01		0.96		1.09	
	1.38	1.39	1.15	1.15	1.02	1.06	1.03	1.02	0.96	0.96	0.96	1.03
5	1.17		0.87		.....		1.08		1.19		....	
	1.12	1.15	0.91	0.89	.. ...	......	1.10	1.09	1.14	1.17	....	....
6	1.48		1.26		0.95		0.98		0.88		0.78	
	1.37	1.43	1.26	1.26	0.99	0.97	0.95	0.96	0.91	0.90	0.85	0.81
Average		1.26		0.95		0.72		0.91		0.95		0.77
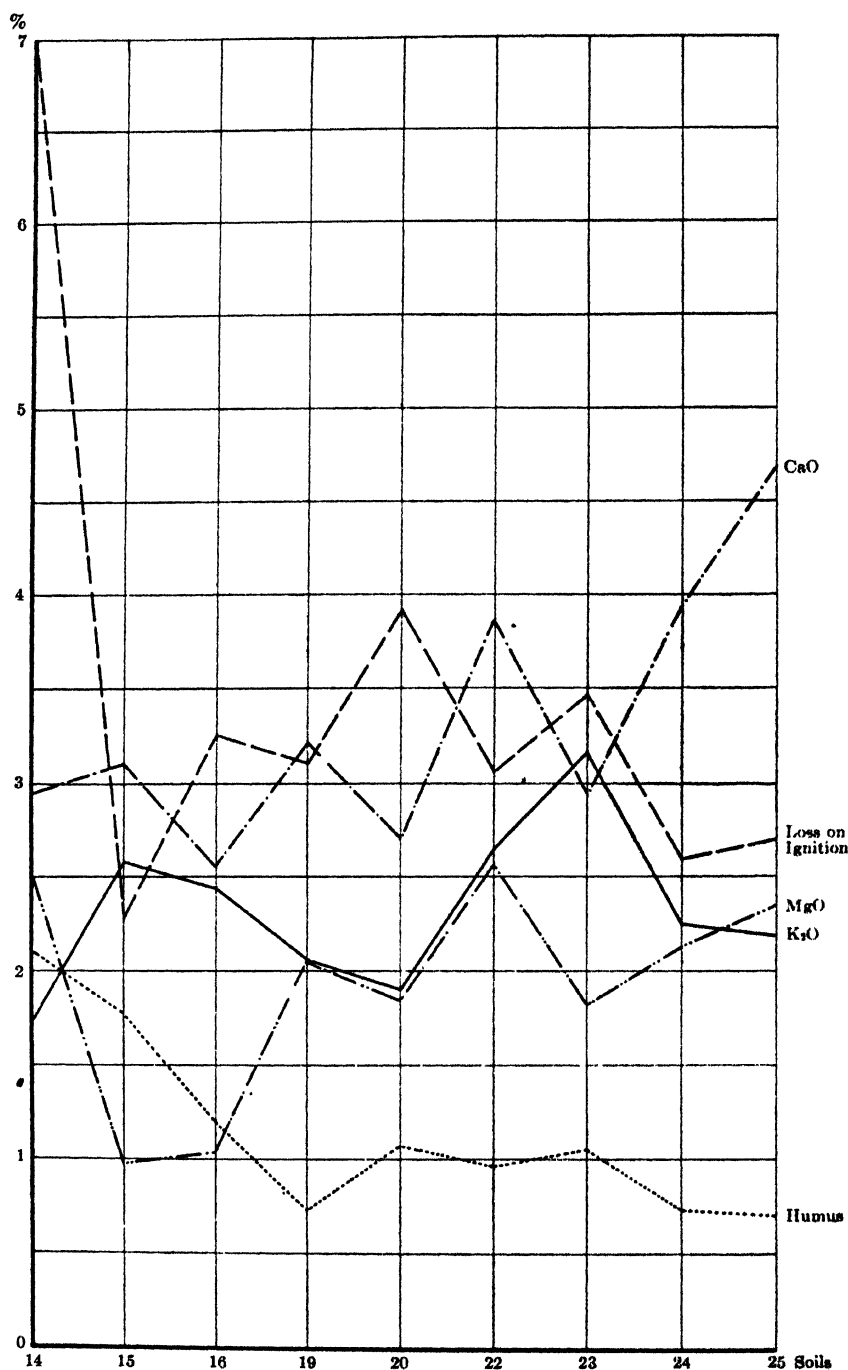
Fig. 18. Graph showing the loss on ignition, the amount of humus, and the percentages of calcium, magnesium, and potassium in the nine samples of Hanford fine sandy loam.

TABLE 17—HUMUS (AND HUMUS ASH)

Altamont Clay Loam

| | Humus Horizons | | | | | | Humus ash Horizons | | | | | |
Sample	A %	Average %	B %	Average %	C %	Average %	A %	Average %	B %	Average %	C %	Average %
3	1.06		0.89		0.59		1.29		1.08		0.95	
	1.13	1.09	0.84	0.86	0.58	0.59	1.23	1.26	1.28	1.18	0.95	0.95
4	1.30		0.69		0.59		0.80		0.98		0.91	
	1.33	1.31	0.71	0.70	0.28	0.43	0.85	0.83	0.98	0.98	1.03	0.97
7	1.32		0.95		0.68		0.72		0.87		1.09	
	1.31	1.32	0.96	0.96	0.68	0.68	0.75	0.74	0.88	0.88	1.08	1.08
Average		1.24		0.84		0.57		0.94		1.01		1.00

TABLE 18—HUMUS (AND HUMUS ASH)

San Joaquin Sandy Loam

| | Humus Horizons | | | | | | Humus ash Horizons | | | | | |
Sample	A %	Average %	B %	Average %	C %	Average %	A %	Average %	B %	Average %	C %	Average %
10	0.66		0.53		0.27		1.31		1.33		0.67	
	......	0.66	......	0.53	......	0.27	......	1.31	. ..	1.33	......	0.67
11	0.75		0.41		0.37		0.51		0.66		0.58	
	0.71	0.73	......	0.41	......	0.37	0.69	0.60	......	0.66	......	0.58
12	0.62		0.49		0.32		0.88		1.50		0.80	
	0.65	0.64	......	0.49	......	0.32	0.95	0.91	......	1.50	......	0.80
13	0.75		0.50		0.35		1.38		0.90		1.02	
	0.78	0.77	......	0.50	......	0.35	1.36	1.37	......	0.90	......	1.02
17	0.51		0.38		......		0.53		1.23		......	
	0.51	0.51	......	0.38	......	......	0.57	0.55	.. ...	1.23	.. ...	......
18	0.56		0.60		0.42		0.61		0.76		1.79	
	0.60	0.58	0.58	0.59	......	0.42	0.56	0.59	0.75	0.76	......	1.79
21	0.52		0.19		0.18		0.53		0.37		0.37	
	0.52	0.52	0.21	0.40	0.21	0.19	0.54	0.53	0.37	0.37	0.48	0.42
26	1.04		0.79		0.68		0.89		3.57		5.28	
	1.01	1.02	0.79	0.79	0.82	0.75	0.76	0.83	3.63	3.60	5.46	5.35
Average		0.66		0.51		0.38		0.83		1.24		1.51
Excluding no. 26		......		......		......		. .....		0.95		0.87

LOSS ON IGNITION

The loss on ignition of the A horizon varies directly with the texture of the soil, the heavier soils losing more on heating. Obviously the water of combination of the clay is a large factor in this loss. In the San Joaquin sandy loam the loss on ignition was determined in the three horizons. In the other three types the A horizon was the only one examined (tables 20, 21, and figs. 15–18).

TABLE 19—HUMUS (AND HUMUS ASH)

Hanford Fine Sandy Loam

Sample	Humus Horizons A %	Average %	B %	Average %	C %	Average %	Humus ash Horizons A %	Average %	B %	Average %	C %	Average %
14	2.11		1.81		1.10		1.14		1.24		1.01	
	2.09	2.10	1.78	1.79	1.05	1.07	1.17	1.16	1.27	1.26	1.09	1.05
15	1.79		0.88		1.04		1.88		0.94		0.92	
	1.77	1.78	0.93	0.90	0.67	0.86	1.85	1.86	0.89	0.92	0.91	0.92
16	1.20		0.73		0.41		0.91		0.93		0.90	
	1.20	1.20	0.73	0.73	0.46	0.44	0.91	0.91	1.47	0.93	0.90	0.90
19	0.73		0.51		0.45		0.48		0.57		0.78	
	0.74	0.73	0.50	0.51	0.55	0.50	0.47	0.48	0.58	0.58	0.76	0.77
20	1.08		0.86		0.59		0.52		0.90		0.79	
	1.06	1.07	0.89	0.88	0.50	0.55	0.56	0.54	0.90	0.90	0.78	0.78
22	0.96		0.73		0.58		0.59		0.60		0.58	
	0.96	0.96	0.71	0.72	0.56	0.57	0.59	0.59	0.60	0.60	0.63	0.61
23	1.04		0.59		0.38		0.58		0.45		0.39	
	1.07	1.05	0.62	0.61	0.38	0.38	0.57	0.58	0.41	0.43	0.37	0.38
24	0.73		0.55		0.56		0.58		0.69		0.82	
	0.73	0.73	0.61	0.58	0.51	0.54	0.56 ·	0.57	0.69	0.69	0.80	0.81
25	0.71		0.58		0.45		0.57		0.67		0.74	
	0.69	0.70	0.56	0.57	0.42	0.44	0.61	0.59	0.71	0.69	0.78	0.76
Average		1.15		0.82		0.59		0.81		0.78		0.78

Diablo clay adobe.—The variation in these samples was from 5.6% to 8.6%, with the average of 6.8%. The Altamont clay loam has a variation of from 5% to 8.7%, averaging 6.7%. The San Joaquin sandy loam has a range of variation between 1.6% and 4.2%, with an average of 2.6%. The loss on ignition of the lower horizons increases over that of the surface, because of the increase in texture. The B horizon shows an average loss of 3.9% and the C horizon of 4.67%. The Hanford fine sandy loam range of variation in the loss on ignition is, excluding no. 14, from 2.2% to 3.9%, with an average of 3.4%. Thus the curve for this type is quite uniform, except for no. 14, which shows a loss of 6.9%.

It is seen that the averages in the loss on ignition of the A horizons of the Diablo and Altamont soils are close, and high, 6.8% and 6.7% respectively. The averages of the San Joaquin and Hanford samples, 2.6% and 3.4% respectively, are low and not widely separated. Since the values for the types overlap considerably, and the averages are not distinct, except between the light and heavy groups, there is no significant distinction between the four types by this determination.

TABLE 20—LOSS ON IGNITION

(Surface horizon only)

Diablo Clay Adobe			Altamont Clay Loam			Hanford Fine Sandy Loam		
	%	%		%	%		%	%
1–A	6.62		3–A	8.74		14–A	6.90	
	6.66	6.64		8.82	8.78		6.95	6.92
2–A	6.57		4–A	5.05		15–A	2.27	
	6.64	6.60		5.05	5.05		2.30	2.28
5–A	5.61		7–A	6.58		16–A	3.26	
	......	5.61		6.46	6.52		3.24	3.25
6–A	8.67			Average	6.78	19–A	3.10	
	8.71	8.69					3.13	3.11
	Average	6.88				20–A	3.90	
							3.94	3.92
						22–A	3.06	
							3.07	3.06
						23–A	3.48	
							3.45	3.46
						24–A	2.60	
							2.60	2.60
						25–A	2.68	
							2.72	2.70
							Average	3.48

TABLE 21—LOSS ON IGNITION

San Joaquin Sandy Loam

			Horizon				
Sample	A %	Average %	B %	Average %	C %	Average %
10	2.13		2.32		3.10	
	2.17	2.15	2.27	2.29	3.08	3.09
11	3.23		6.33		6.57	
	3.20	3.21	6.16	6.24	6.67	6.62
12	5.37		2.97		......	
	3.22	4.29	3.18	3.07	5.54	5.54
13	2.94		6.58		3.97	
	2.96	2.95	6.75	6.66	6.07	5.02
17	1.85		2.54		No sample	
	1.88	1.86	2.61	2.57		
18	1.82		2.18		2.90	
	1.83	1.82	2.18	2.18	2.89	2.89
21	1.68		1.60		3.31	
	1.69	1.68	1.56	1.58	3.33	3.32
26	3.30		6.97		6.18	
	......	3.30	6.95	6.96	......	6.18
	Average	2.66		3.94		4.67

CALCIUM

The Diablo, Altamont, and Hanford soils were analyzed for their calcium in the A horizon only, while the A, B, and C horizons of the San Joaquin sandy loam were analyzed (tables 22, 23, and figs. 15–18).

Diablo clay adobe.—There is much divergence in the amounts of CaO in this type, varying from 0.36% to 2.05%, with the average of 1.23%.

Altamont clay loam.—In this type there is a little greater variation than in the Diablo samples, with a range of from 0.78% to 5.64%, averaging 2.44% CaO. In both this soil and in the Diablo the wide variation in the lime content is undoubtedly due to the nature of the parent rock, since the soils are residual.

San Joaquin sandy loam.—In the CaO content there is no uniformity among the samples. The A samples of this type contain from 0.47% to 2.98%, with an average of 1.65%. It would seem that the materials from which the soils were derived were of varying composition. For from the present climatic conditions soil no. 25 is the one subject to the least leaching, and yet has the least CaO content. The B and C percentages follow the surface very closely—sufficiently so to necessitate no particular explanation. The range of variation in the B horizon is from 0.11% to 2.42%, and the average is 1.42%. The C samples vary from 0.17% to 2.81%, with the average of 1.52%.

Hanford fine sandy loam.—The A samples of this type contain from 2.56% CaO to 4.69%, with 3.33% as the average. The variations are not so marked among the series of this type as in the cases of the other three soils. The absolute range is nearly as great, but the relative variation is less.

Even though there are differences between the average CaO content in the several types, the wide variation in the amount found in the several samples of a given type, and the overlapping of these amounts from the different types entirely preclude any statement that as regards the calcium content the soils of any one type are closely similar to one another, or that one type has a higher or lower lime content than another.

TABLE 22—CALCIUM AS CaO

(Surface horizons only)

Diablo Clay Adobe	%	%
1–A	1.86	
	1.80	1.83
2–A	2.12	
	1.98	2.05
5–A	0.56	
	0.17	0.36
6–A	0.67	
	......	0.67
Average		1.23

Altamont Clay Loam	%	%
3–A	5.64	
	......	5.64
4–A	0.92	
	0.88	0.90
7–A	0.89	
	0.67	0.78
Average		2.44

Hanford Fine Sandy Loam	%	%
14–A	2.91	
	2.99	2.95
15–A	2.98	
	3.22	3.10
16–A	2.48	
	2.65	2.56
19–A	3.28	
	3.17	3.22
20–A	2.69	
	2.73	2.71
22–A	3.80	
	3.92	3.86
23–A	2.88	
	3.00	2.94
24–A	3.88	
	4.00	3.94
25–A	4.58	
	4.80	4.69
Average		3.33

TABLE 23—CALCIUM AS CaO

San Joaquin Sandy Loam

	Horizon					
Sample	A %	Average %	B %	Average %	C %	Average %
10	0.67		0.82		1.11	
	0.62	0.64	1.03	0.92	1.12	1.11
11	1.94		1.62		1.65	
	1.26	1.60	1.70	1.66	1.55	1.60
12	3.12		2.21		2.61	
	3.50	3.31	......	2.21	3.01	2.81
13	2.83		2.38		2.46	
	3.13	2.98	2.46	2.42	2.79	2.62
17	1.83		1.92		No sample	
	2.08	1.95	2.08	2.00		
18	1.40		1.00		1.48	
	1.34	1.37	1.45	1.22	1.42	1.45
21	0.91		0.89		0.85	
	0.84	0.87	0.83	0.86	0.89	0.87
26	0.48		0.13		0.17	
	0.47	0.47	0.10	0.11	0.17	0.17
Average		1.65		1.42		1.52

MAGNESIUM AS MgO

Diablo clay adobe.—This type shows a moderate variability in the magnesium content, with from 1.13% MgO to 3.26%, averaging 2.09%. The largest quantity is three times that of the smallest (tables 24, 25, figs. 15–18).

Altamont clay loam.—Within the three samples of this type the range in the MgO content is very great, from 0.07% to 1.90%, with the average of 1.05%. The largest is twenty-seven times that of the smallest.

San Joaquin sandy loam.—The total MgO in the samples of the type is low, considering that some soils reported by Hilgard contain from 1% to 3% magnesia by the acid digestion. The variation within the A horizon is from 0.34% to 0.90%, with the average of 0.62%, i.e., the largest is three times the smallest. The quantities in the B horizon are somewhat erratic as compared with those of the surface, yet in both the B and C horizons the results approach those of the surface sufficiently to give a rough parallelism. The greater amount of clay and fine silts with the increase of depth gives, as one would expect, an increase of magnesium. The average MgO content in the B horizon is 0.81%, and in the C horizon 1.05%.

TABLE 24—MAGNESIUM AS MgO

(Surface horizon only)

Diablo Clay Adobe			Altamont Clay Loam			Hanford Fine Sandy Loam		
	%	%		%	%		%	%
1–A	1.64		3–A	1.85		14–A	2.49	
	2.20	1.92		1.95	1.90		2.49	2.49
2–A	2.16		4–A	1.21		15–A	0.93	
	1.95	2.05		1.17	1.19		1.02	0.97
5–A	1.23		7–A	0.09		16–A	1.10	
	1.03	1.13		0.05	0.07		0.99	1.04
6–A	3.62		Average		1.05	19–A	2.11	
	2.90	3.26					1.99	2.05
Average		2.09				20–A	1.77	
							1.92	1.84
						22–A	2.44	
							2.71	2.57
						23–A	1.94	
							1.70	1.82
						24–A	2.14	
							2.13	2.13
						25–A	2.31	
							2.40	2.35
						Average		1.92

Hanford fine sandy loam.—The MgO content of the surface soil varies from 0.97% to 2.57%, averaging 1.92%. The relative variation within this type is about that of the Diablo and San Joaquin types.

Comparing the average amounts of magnesium oxide in the surface horizon of the several types, we find the San Joaquin with 0.56%, the Altamont with 1.05%, the Hanford with 1.93%, and the Diablo with 2.09%. The averages do not signify much, however, because of the wide ranges within the types. Therefore as regards magnesium the types are neither distinct nor are the soils within the type closely similar.

TABLE 25—MAGNESIUM AS MgO

San Joaquin Sandy Loam

Horizon

Sample	A %	Average %	B %	Average %	C %	Average %
10–A	0.31		0.33		0.53	
	0.30	0.30	0.45	0.39	0.53	0.53
11–A	0.79		1.21		1.48	
	0.44	0.61	1.22	1.21	1.25	1.36
12–A	0.83		0.79		1.57	
	0.79	0.81	......	0.79	1.62	1.59
13–A	0.90		1.70		1.67	
	0.80	0.85	1.63	1.66	1.82	1.74
17–A	0.53		0.51		No sample	
	0.74	0.63	0.77	0.64		
18–A	0.50		0.40		0.64	
	0.48	0.49	0.69	0.54	0.75	0.69
21–A	0.29		0.28		0.52	
	......	0.29	0.31	0.29	0.56	0.54
26–A	0.50		0.52		0.52	
	0.52	0.51	0.44	0.48	0.53	0.52
Average		0.56		0.75		1.00

PHOSPHORUS AS P_2O_5

Diablo clay adobe.—The variations in the P_2O_5 content in the samples of this type are relatively small, from 0.092% to 0.162%, with 0.108% as the average (tables 26, 27, figs. 11–14).

Altamont clay loam.—The range of variation in the amount of P_2O_5 is large, from 0.031% to 0.265%, the largest quantity being eight times the smallest. The average is 0.132%.

San Joaquin sandy loam.—The variations in the P_2O_5 content of the surface soil are from 0.039% to 0.11%, with the average 0.068%. The curve is fairly regular. The subsoils follow the surface in a general way. The B horizon samples vary in the phosphoric acid content between 0.028% and 0.156%, and average 0.069%. The C samples vary between 0.03% and 0.109%, and average 0.067%. The averages of the three horizons are seen to be almost identical. No particular significance can be attached to the minor variations.

Hanford fine sandy loam.—The P_2O_5 content in the samples of this type is very variable, from 0.195% to 0.819%, with the average of 0.363%. The average of the San Joaquin sandy loam samples is 0.069%, of the Diablo clay adobe 0.108%, of the Altamont clay loam 0.132%, and of the Hanford fine sandy loam 0.363%. Except between the Diablo and Altamont types these averages would show considerable differences, if it were not that the samples frequently show such wide departures from the averages. The ranges of the several types frequently overlap.

TABLE 26—PHOSPHORUS AS P_2O_5

(Surface horizon only)

Diablo Clay Adobe			Altamont Clay Loam		Hanford Fine Sandy Loam		
	%	%		%	%	%	%
1–A	0.088		3 A	0.278	14–A	0.373	
	0.096	0.092		0.252	0.265	0.292	0.333
2–A	0.064		4–A	0.081	15–A	0.287	
	0.078	0.071		0 117	0.099	0.260	0.273
5–A	0.137		7–A	0 034	16–A	0.260	
	0 082	0.109		0.028	0.031	0.277	0.268
6–A	0.143		Average	0.132	19–A	0.303	
	0.181	0.162				0.272	0.287
Average		0.108			20–A	0.190	
						0.200	0.195
					22- A	0.397	
						0.401	0.399
					23–A	0.242	
						0.270	0.256
					24–A	0.421	
						0.454	0.437
					25–A	0.879	
						0.759	0.819
					Average		0.363

TABLE 27—PHOSPHORUS AS P_2O_5

San Joaquin Sandy Loam

Sample	Horizon					
	A %	Average %	B %	Average %	C %	Average %
10	0.118		0.060		0.047	
	0.102	0.110	0.068	0.064	0.057	0.052
11	0.049		0.047		0.049	
	0.060	0.054	0.046	0.046	0.028	0.028
12	0.057		0.028		0.064	
	0.071	0.064	... .	0.028	0.095	0.078
13	0.049		0.037		0.036	
	0.064	0.056	0.038	0.039	0.024	0.030
17	0.036		0.041		No sample	
	0.042	0.039	0.082	0.061		
18	0.043		0.097		0.086	
	0.055	0.049	0.074	0.085	.	0.086
21	0.069		0.088		0.094	
	0.068	0.068	0.066	0.077	0.062	0.078
26	0.117		0.130		0.120	
	0.092	0.104	0.182	0.156	0.098	0.109
Average		0.068		0.069		0.067

POTASSIUM AS K_2O

Diablo clay adobe.—There is a moderate range in the variation in the amount of K_2O within this type, the lowest amount being 1.48% and the highest 2.06%, the four samples averaging 1.71% (table 28, figs. 15–18).

Altamont clay loam.—A greater variation, from 1.09% to 2.14%, of K_2O, occurs in the three samples of this type. The average is 1.74%.

San Joaquin sandy loam.—This type shows the greatest variation, from 0.98% to 2.84%. But even so, the the largest quantity of K_2O is less than three times the smallest. 1.88% K_2O is the average of the eight samples. Nos. 11 and 12 of this type show the smallest amounts of K_2O of any of the twenty-four samples.

Hanford fine sandy loam.—The variation in the K_2O content of the samples of this type is not great—from 1.73% to 3.16%, with the average of 2.33%. This is the highest average, as the Diablo clay adobe samples show 1.71%, the Altamont clay loam 1.74%, and the San Joaquin sandy loam 1.88%. Because of the considerable range in the amounts of K_2O for the several samples of a type, and because of the many overlappings of the values for one type over another, the averages do not mean much and do not show the soils within a type to be closely similar, nor do they show the types distinct.

TABLE 28—POTASSIUM AS K₂O

(J. Lawrence Smith Method)

Diablo Clay Adobe			Altamont Clay Loam			San Joaquin Sandy Loam			Hanford Fine Sandy Loam		
No.	%	Average %	No.	%	Average %	No.	%	Average %	No.	%	Average %
1-A	1.68		3-A	1.06		14-A	1.79		10-A	2.14	
	1.67	1.67		1.13	1.09		1.67	1.73		2.12	2.13
2-A	1.62		4-A	1.92		15-A	2.54		11-A	0.99	
	1.69	1.65		2.36	2.14		2.62	2.58		0.98	0.98
5-A	1.45		7-A	1.90		16-A	2.42		12-A	1.03	
	1.51	1.48		2.10	2.00		2.46	2.44		1.02	1.02
6-A	2.01			Average	1.74	19-A	2.10		13-A	1.50	
	2.12	2.06					2.03	2.06		.....	1.50
	Average	1.71				20-A	2.00		17-A	2.40	
							1.81	1.90		2.24	2.32
						22-A	2.68		18-A	2.07	
							2.62	2.65		2.28	2.17
						23-A	3.10		21-A	2.81	
							3.23	3.16		2.88	2.84
						24-A	2.29		26-A	2.04	
							2.21	2.25		2.09	2.06
						25-A	2.18			Average	1.88
							2.21	2.19			
							Average	2.33			

BACTERIOLOGICAL DATA

The bacteriological work was not entirely satisfactory, partly be-cause the conditions in one of the incubators were not all that might be desired, and partly because of the refractory physical properties of some of the soils. The Diablo and Altamont types, in all three horizons, were very heavy and hard to mix and keep in even fair physical condition. The San Joaquin soils were predominantly of a heavy texture in the B and C horizons, while the surface horizon was light and the crumb structure was entirely lost if even a *small* excess of water was added to the culture.

AMMONIFICATION

There are very marked differences between the various types in this determination, though the samples in a given type vary among themselves to a large extent.

Diablo clay adobe.—The highest ammonia production was about three times the lowest, 7.7 mg. and 26 mg. In both this type and the following, the B and C horizons follow the surface horizon quite
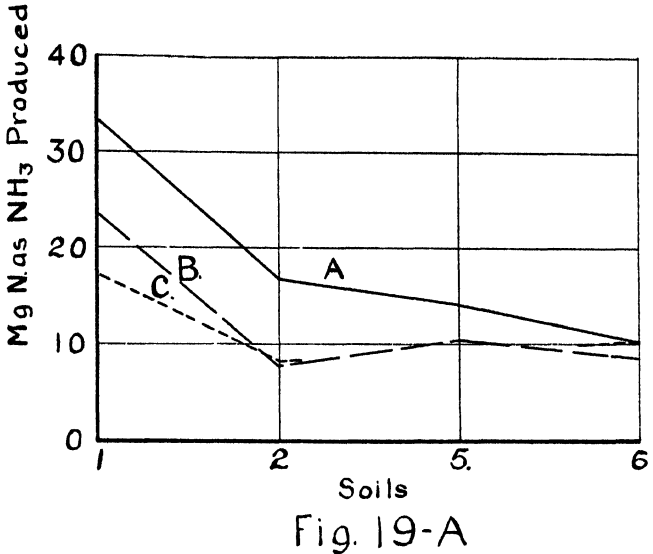
Fig. 19-A

Fig. 19A. Graph showing ammonification in the four samples of Diablo clay adobe. The quantities are expressed in terms of nitrogen produced per 100 grams of soil with 2% of dried blood.
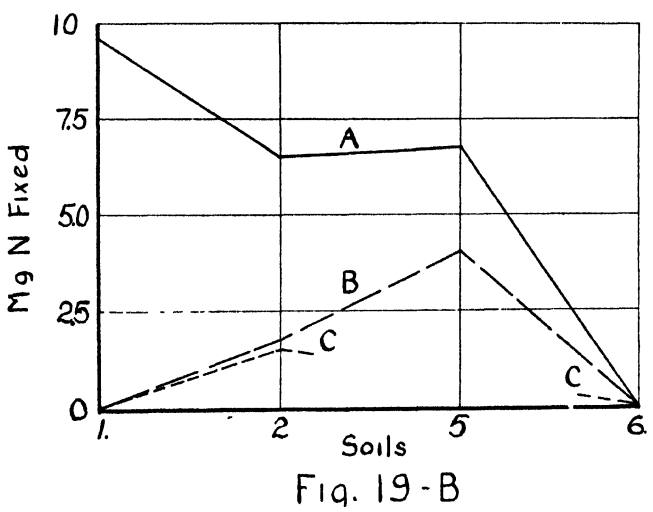
Fig. 19-B

Fig. 19B. Graph showing nitrogen fixation in the three horizons of the four samples of Diablo clay adobe. The quantities are expressed in terms of milligrams of nitrogen fixed per gram of mannite in 50 grams of soil.

closely from sample to sample (table 28 and fig. 19A). This may be due to the textures, which are quite similar throughout the soil column. The averages for the three horizons were: A, 18.6 mg.; B, 12.6 mg.; and C, 8.9 mg.
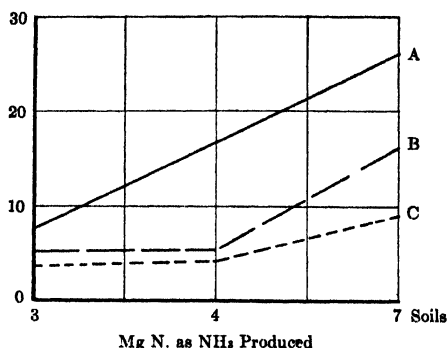
Fig. 20A. Graph showing ammonification in the three horizons of the three samples of Altamont clay loam.
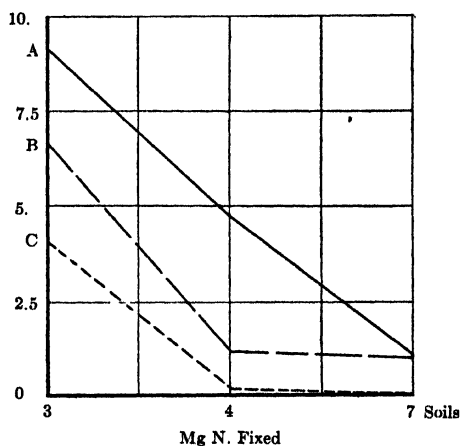
Fig. 20B. Graph showing nitrogen fixation in milligrams in the three horizons of the three samples of Altamont clay loam.

Altamont clay loam.—As regards horizon A the amount of ammonia produced in one soil is three times that in the lowest, 10 mg. nitrogen and 33 mg. nitrogen as ammonia, with 8.9 mg. as the average (table 30 and fig. 20A). The amount of nitrogen as ammonia produced in the B horizon averaged 12.6 mg., in the C horizon 8.9 mg.

San Joaquin sandy loam.—The amount of ammonia produced in the A horizon varied between 30.4 mg. of nitrogen and 57.1 mg., the average was 40.2 mg. (table 31 and fig. 21A). The production of ammonia, in milligrams of nitrogen, by the B samples varied between 4.5 mg. and 38.1 mg., with 20 mg. as the average. In the C samples the variation was nearly as great, between 5.7 mg. and 32 mg., with the average of 20.9 mg. Thus there are notable variations among the
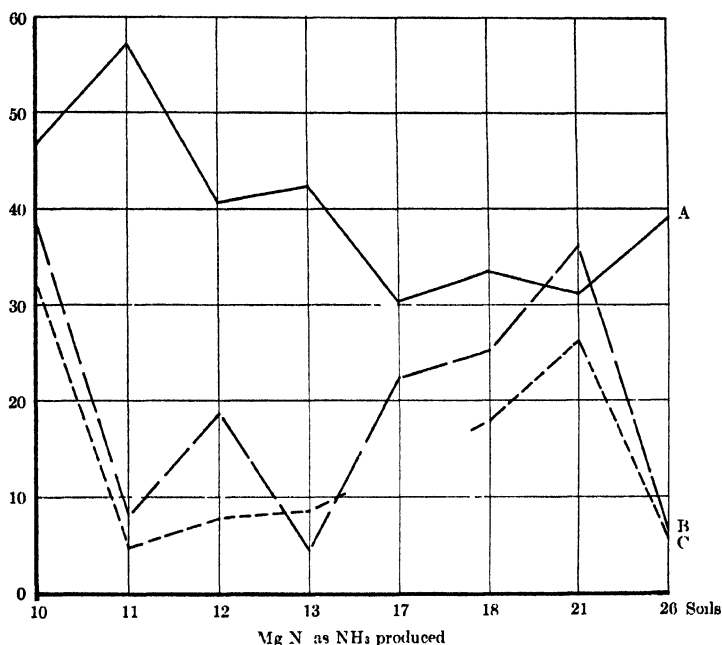
Fig. 21A. Graph showing ammonification in the three horizons of the eight samples of San Joaquin sandy loam.

samples of this type, the proportional variation being very great, considering the three horizons. Possibly the reason that the B and C horizons are so divergent from the surface is that there is a very marked variation in the texture between the surface horizon and those below the surface.

Hanford fine sandy loam.—The variation is large here also (table 32, fig. 22A), the largest quantity of ammonia produced in the surface soil is twice that of the smallest production, 72 mg. and 35 mg. The subsoil variations, in a general way, parallel those of the surface. The average production of ammonia in the three horizons is as fol-

lows: A, 56.9 mg. nitrogen; B, 46.3 mg. nitrogen; and C, 38.7 mg. nitrogen. In attempting to correlate the variations in ammonifying powers with the known variations of the soils, or with the known histories of the soils, there seem to be no relations of significance.

The Altamont and Diablo types are about alike in their low ammonifying power. The Hanford and San Joaquin are both higher and nearer to each other than to the two heavy types, yet the Hanford is noticeably higher than the San Joaquin. This is as one would expect, from a knowledge of the soils in the field. Considering the types as a whole, as represented by the A horizon, there are more marked variations between the types than between the samples of a given type though the variations within a given type are very large.

TABLE 29—AMMONIFICATION

Diablo Clay Adobe

Milligrams N as NH₃ Produced

Sample	A			B			C		
	Cultures	Checks average	Increase over checks	Cultures	Checks average	Increase over checks	Cultures	Checks average	Increase over checks
1	31.48			28.58			24.24		
	40.32	2.52	33.38	22.98	2.28	23.50	14.99	2.42	17.19
2	19.81			9.45		.	8.41		
	17.07	1.68	16.76	9.84	1.91	7.73	9.95	1.05	8.13
5	15.90			11.55			No sample		
	....	1.75	14.15	12.54	1.54	10.50			
6	12.33			7.76			12.33		
	....	2.11	10.22	13.55	2.07	8.58	12.33	2.03	10.30
Average			18.63			12.58			11.87

TABLE 30—AMMONIFICATION

Altamont Clay Loam

Milligrams N as NH₃ Produced

Sample	A			B			C		
	Cultures	Checks average	Increase over checks	Cultures	Checks average	Increase over checks	Cultures	Checks average	Increase over checks
3	8.14			6.97			5.89		
	10.58	1.68	7.68	7.15	1.40	5.16	4.91	1.54	3.86
4	19.75			6.59			5.41		
	19.12	2.66	16.77	6.67	1.36	5.27	5.12	1.19	4.07
7	28.66			19.66			8.00		
	27.53	2.03	26.06	16.25	1.75	16.20	12.37	1.33	8.95
Average			16.84			8.88			5.63

TABLE 31—AMMONIFICATION

San Joaquin Sandy Loam

Milligrams N as NH₃ Produced

	A			B			C		
Sample	Cultures	Checks average	Increase over checks	Cultures	Checks average	Increase over checks	Cultures	Checks average	Increase over checks
10	54.24			42.63			28.89		
	41.95	1.72	46.73	36.11	1.28	38.09	38.25	1.59	31.98
11	44.47			7.47			6.05		
	73.23	1.70	57.15	12.52	1.81	8.18	6.78	1.68	4.78
12	44.48			18.73			10.91		
	40.07	1.56	40.71	21.81	1.50	18.77	6.11	1.14	7.87
13	41.66			5.41			3.80		
	45.94	1.30	42.50	5.36	0.86	4.52	15.17	0.88	8.60
17	30.19			27.59			No sample		
	33.88	1.66	30.37	20.68	1.51	22.62			
18	35.04			30.56			21.96		
	35.24	1.48	33.66	22.81	1.30	25.38	16.92	1.47	17.97
21	34.44			37.41			25.72		
	30.89	1.48	31.18	37.74	1.38	36.19	29.66	1.42	26.27
26	40.81			7.50			9.08		
	.. ..	1.64	39.17	8.41	1.44	6.51	5.43	1.54	5.71
Average			40.18			20.03			12.89

TABLE 32—AMMONIFICATION

Hanford Fine Sandy Loam

Milligrams N as NH₄ Produced

	A			B			C		
Sample	Cultures	Checks average	Increase over checks	Cultures	Checks average (Horizons)	Increase over checks	Cultures	Checks average	Increase over checks
14	37.35			27.96			14.39		
	43.57	1.78	38.68	48.46	1.46	36.75	41.70	1.24	26.80
15	33.11			45.68			59.90		
	41.75	1.75	35.68	48.38	1.70	45.33	52.59	1.62	54.62
16	56.59			44.08			44.58		
	56.77	1.83	54.85	42.10	1.61	41.48	52.10	1.69	46.65
19	52.92			46.70			24.56		
	51.85	1.47	50.91	38.92	1.13	41.68	28.12	1.24	25.10
20	72.49			45.49			22.05		
	74.21	1.36	71.99·	38.52	1.03	40.97	30.35	1.00	25.20
22	64.92			57.44			46.08		
	67.56	1.75	64.49	55.34	1.51	54.88	47.55	1.60	45.21
23	71.56			50.84			35.15		
	68.66	1.61	68.50	43.01	1.37	45.55	35.23	1.35	33.84
24	65.02			50.09			37.56		
	59.51	1.50	60.76	46.54	1.32	46.99	40.21	1.33	37.55
25	68.20			69.29			61.01		
	67.29	1.43	66.31	60.03	1.25	63.41	47.70	1.22	53.13
Average			56.91			46.34			38.67

NITROGEN FIXATION[28]

Diablo clay adobe.—This type shows the highest quantity of nitrogen fixed, 9.6 mg., with the subsoil quantities, much lower than the surface. The variation within the type is seen to be the largest of that in any of the types.

Altamont clay loam.—The surface samples have 1.0, 4.7, and 9.1 mg. nitrogen (table 34 and fig. 20B). The soils shows a wide divergence between the surface samples and between the surface and subsoils. This is to be expected in the heavier soils.
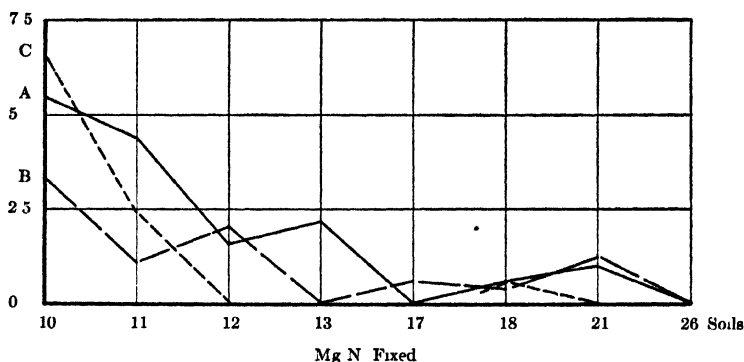
Fig. 21B. Graph showing nitrogen fixation in the three horizons of the eight samples of San Joaquin sandy loam.

San Joaquin sandy loam.—The quantity fixed in the A horizon (table 35 and fig. 21B) is small and quite variable. It is between nothing and 5.5 mg., with the average of 1.9 mg. Instead of nitrogen fixation denitrification took place in a number of cases, especially in horizon C. Considering the wide variation in textures of the horizons, it is rather odd that there should not be a greater variation between the soils from the various depths.

Hanford fine sandy loam.—The amount of nitrogen fixed by the surface soil (table 36, and fig. 22B) averages much higher, 5.7 mg., than that in the San Joaquin sandy loam, though the range of variation is about the same. It is noticeable that the amounts of nitrogen fixed by the B and C horizons of the soils nos. 14 and 19 are much

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[28] All of the figures on nitrogen fixation refer to the milligrams of nitrogen fixed per gram of mannite in 50 grams of soil (table 33 and figs. 9–13).

less (even to denitrification) absolutely and relatively as compared with the surface horizons, than the amount fixed by the B and C horizons of the soils nos. 20 to 25 inclusive.

Comparing the nitrogen fixation of the various types, there seem to be no characteristic differences between the heavy Altamont and Diablo types, while the lighter Hanford and San Joaquin types are considerably different from each other. As a whole there is but a fair degree of similarity between the samples of a given type. The degree of variation within types is large.

TABLE 33—NITROGEN FIXATION

Diablo Clay Adobe

Milligrams N per gram of mannite

	A			B			C		
Sample	Cultures	Checks average	Increase over checks	Cultures	Checks average	Increase over checks	Cultures	Checks average	Increase over checks
1	60.25			31.52			22.77		
	63.40	52.22	9.60	29.56	34.67	−4.13	24.87	28.61	−4.79
2	55.34			32.92			30.47		
	49.39	45.88	6.48	38.18	33.80	1.75	32.22	29.77	1.57
5	48.68			35.73			No sample		
	48.68	41.92	6.76	37.12	32.39	4.03			
6	45.88			39.64			35 02		
	46.86	58.49	−12.12	42.72	50.77	−9 59	39.01	39.05	−2.03
Average			4.71			1.44			0.52

TABLE 34—NITROGEN FIXATION

Altamont Clay Loam

Milligrams N fixed per gram of mannite

	A			B			C		
Sample	Cultures	Checks average	Increase over checks	Cultures	Checks average	Increase over checks	Cultures	Checks average	Increase over checks
3	71.26			49.04			37.13		
	70.40	61.71	9.12	51 84	43.78	6.66	38.51	33.76	4.06
4	60.25			28.02			20.31		
	52.19	51.49	4.73	27.32	26.48	1.19	21.01	20.48	0.18
7	52.95			37.75			30.81		
	53.44	52.12	1.08	37.40	36.60	1.00	27.18	29.94	−0.94
Average			4.98			2.95			1.41
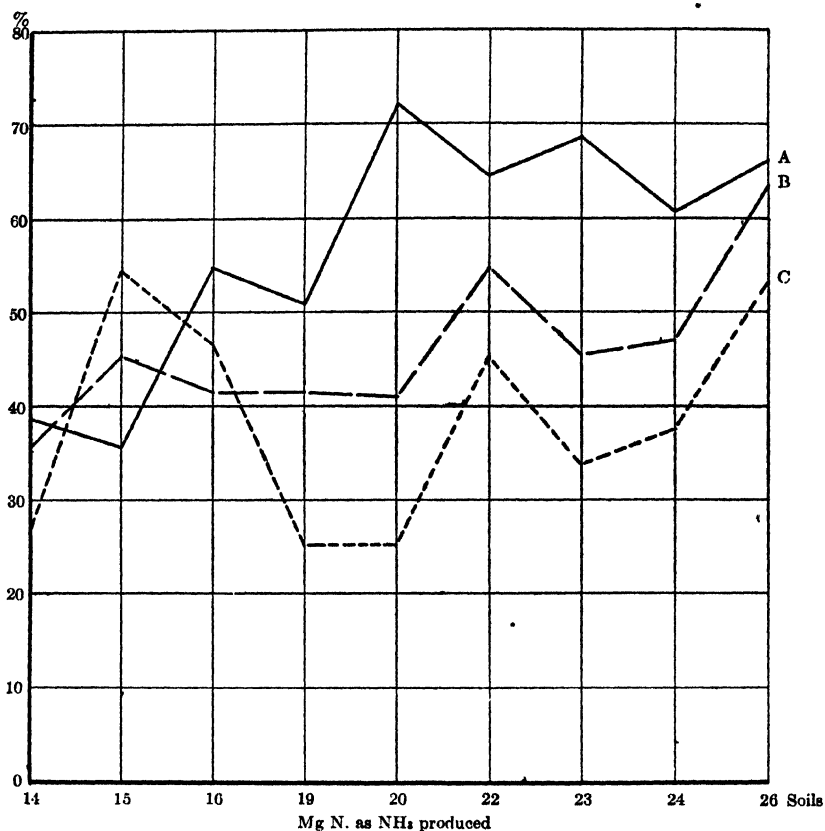
Fig. 22A. Graph showing ammonification in the three horizons of the nine samples of Hanford fine sandy loam.
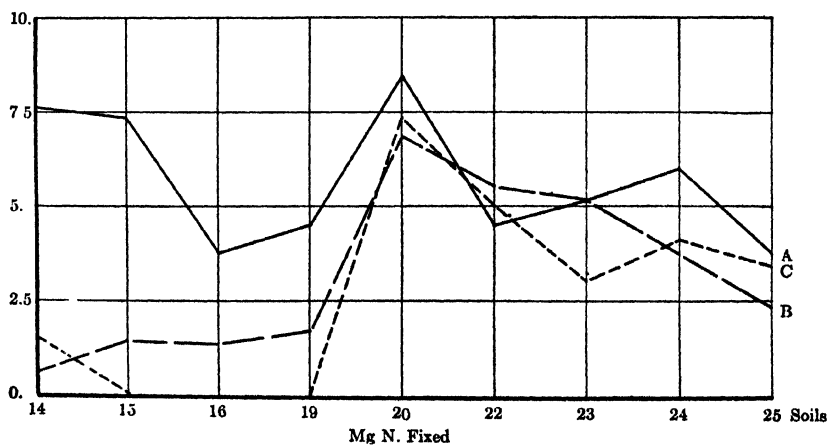
Fig. 22B. Graph showing nitrogen fixation in the three horizons of the nine samples of Hanford fine sandy loam.

TABLE 35—NITROGEN FIXATION

San Joaquin Sandy Loam

Milligrams N fixed per gram of mannite

Sample	A Cultures	Checks average	Increase over checks	B Cultures	Checks average	Increase over checks	C Cultures	Checks average	Increase over checks
10	25.01			17.16			15.83		
	23.47	18.73	5.51	16.67	13.59	3.32	18.14	10.33	6.65
11	27.25			22.91			21.72		
	31.87	25.15	4.41	22.84	21.78	1.09	22.00	19.43	2.43
12	25.85			20.17			18.98		
	23.82	23.26	1.57	17.09	16.56	2.07	20.10	20.41	-0.87
13	22.77			18.49			13.31		
	21.58	20.00	2.17	17.86	20.21	-2.04	14.50	16.35	-2.45
17	13.52			9.46			No sample		
	13.45			10.23					
18	15.55			8.76			9.18		
	13.24	13.73	0.66	8.20	8.09	0.39	11.42	9.74	0.56
21	14.85			7.98			6.58		
	16.11	14.50	0.98	6.44	5.96	1.25	7.28	7.01	-0.07
26	19.54			12.61			7.14		
	19.34	20.34	-0.94	12.82	13.34	-0.72	7.36	8.24	-0.99
Average			1.91			1.09			1.20

TABLE 36—NITROGEN FIXATION

Hanford Fine Sandy Loam

Milligrams N fixed per gram of mannite

Sample	A Cultures	Checks average	Increase over checks	B Cultures	Checks average	Increase over checks	C Cultures	Checks average	Increase over checks
14	71.52			41.61			31.10		
	63.05	59.61	7.67	41.69	41.01	0.64	30.19	29.07	1.57
15	38.18			22.07			12.40		
	29.56	26.55	7.32	21.09	20.12	1.46	14.08	13.87	-0.63
16	30.33			16.46			9.67		
	32.92	27.84	3.78	16.04	14.85	1.40	8.97	10.61	-1.29
19	25.56			14.43			11.77		
	26.41	22.49	4.49	13.59	12.29	1.72	12.33	11.80	-0.25
20	38.04			22.84			17.09		
	38.11	29.66	8.41	23.61	16.39	6.83	20.6ʋ	11.52	7.32
22	35.59			22.20			17.30		
	31.80	29.17	4.52	23.40	17.23	5.57	16.46	11.87	5.01
23	38.95			19.19			11.90		
	43.57	36.10	5.16	20.25	14.57	5.15	11.98	8.90	3.04
24	28.79			19.89			18.52		
	34.61	25.67	6.03	21.52	16.95	3.75	17.51	13.91	4.11
25	26.55			17.86			15.55		
	26.41	22.70	3.78	17.93	15.51	2.38	13.87	11.31	3.41
Average			5.69			3.21			2.27

NITRIFICATION[29]

The most noticeable thing about the nitrification results is the very wide range of variation in the various representatives of the Hanford fine sandy loam as compared with the quite uniform and consistent results obtained with the other types.

Diablo clay adobe.—The percentage of nitrogen nitrified (table 37, 38, and fig. 23) is uniformly low. The B samples showed a less vigorous nitrifying flora (except in the case of no. 6) than the surface ones. Dried blood in the quantities used seems to depress the

A S N +Cottonseed Meal

A S N + (NH₄)₂SO₄

A S N + Dried Blood

A Soil Nitrogen

Percentages of N Nitrified
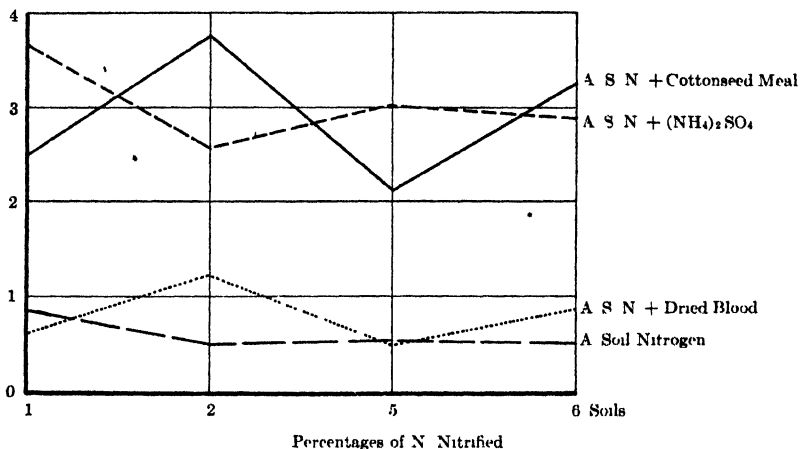
Fig. 23. Graph showing the percentages of nitrogen in various nitrogen containing materials nitrified in the four samples of the Diablo clay adobe.

normal activity (A horizon average 0.81%), while the $(NH_4)_2SO_4$ (A horizon average 3.03%) and the cottonseed meal (A horizon average 2.91%), as compared with the incubated control tend to increase the percentage of nitrogen nitrified. It should be kept in mind that an absolute increase in the nitrogen content may accompany a decrease in the percentage, due to the greatly increased amount of nitrogen present after the addition of a nitrogenous substance. The variation of the samples within this type is very moderate as compared with the San Joaquin and Hanford types.

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[29] The figure, used in the discussion shows the percentages of the nitrogen in the cultures which were nitrified. There are two tables for the samples of each type. The percentages of nitrogen nitrified are rearranged in a second table for greater ease in comparing results.

Altamont clay loam.—The percentages of nitrogen nitrified (tables 39 and 40, fig. 24) are as a whole lower than in the Diablo soils. A similar relative effect of the several nitrogenous materials is seen, for $(NH_4)_2SO_4$ is first, cottonseed meal, second, the soil's own nitrogen third, and dried blood fourth in the percentages of nitrates produced. As in the Diablo soils the variation is not great from soil to soil.

San Joaquin sandy loam.—A wide range of variation (tables 41, 42, and fig. 25), from 1.2% to 4.5%, is found in the incubated control, possibly due, in part, to the considerable variations in the physical nature of the samples. The relative action of the nitrogenous ma-
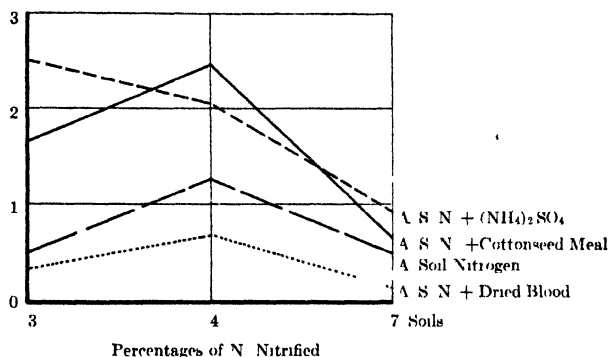
Fig. 24. Graph showing the percentages of nitrogen in various nitrogen containing materials nitrified in the three samples of the Altamont clay loam.

terials in the soils of the San Joaquin samples as compared with that in the Diablo and Altamont soils is well shown by the following aver-ages of the A horizon: dried blood had 0.02%, cottonseed meal had 0.33%, and ammonium sulfate had 0.56% of the nitrogen nitrified, while the incubated control had 2.47% nitrified. The soils are normally low in nitrogen, and this, together with the poor physical condition, made an unfavorable medium for any bacterial activity. This applies especially to horizons B and C.

Hanford fine sandy loam.—This is by far the most inexplicable set of results in the nitrification studies (tables 43, 44, and fig. 26). The physical nature of this type is admirably suited for bacteriological tumbler cultures, the soil being friable, not puddling readily, and while in the incubator may be kept at the approximately optimum moisture content with little difficulty. This property is fairly con-

stant throughout all the samples (except no. 14) and cannot well
be supposed to affect the results greatly. No. 14 has a low nitrifying
power throughout, but it is not representative of the type, for it is
heavier in texture than the rest. Moreover, it had been submerged
by river overflows shortly before the collection of the sample. One
would expect these factors to influence the numbers and the activity
of the bacterial flora. There is but little similarity in the way the
different samples of the A or B horizons behave toward any given
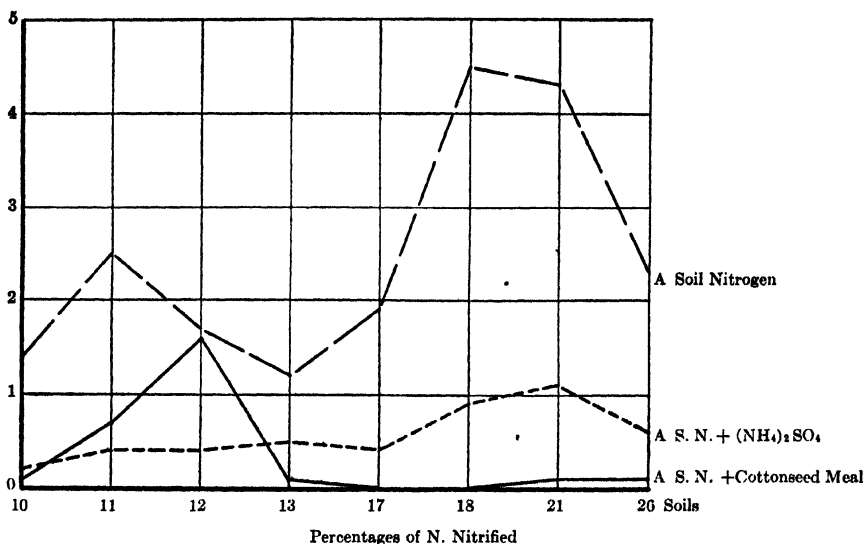
Fig. 25. Graph showing the percentages of nitrogen in various nitrogen
containing materials nitrified in the eight samples of the San Joaquin sandy
loam.

nitrogen containing material. Variations from 1% to 50%, from
0% to 14%, from 4.5% to 8%, or from 15% to 15.5% from soil to
soil, without regularity, give slight basis for generalizations. The
average effect of the A horizon samples of the Hanford fine sandy
loam as regards the several nitrogenous materials is as follows: dried
blood, 5.62%; cottonseed meal, 13.72%; ammonium sulfate, 3.29%;
incubated control, 1.55%. In a general way there is a similarity
between the effects of a given nitrogen containing material on the
surface sample, and on the B horizon. This should be so, since these
soils are very deep and uniform in texture. However, in the C
horizon there were still greater decreases in the bacterial activity.

As regards nitrification in general there is difficulty in showing any greater resemblance between the samples of a type than there is from type to type. In certain features, however, the types are somewhat distinct: (1) The relation of the nitrification of the soil's own nitrogen to the soil's action upon added nitrogen is rather distinct for the types. The normal soil in the San Joaquin type gave a much larger per cent of nitrogen than did the soil plus the added nitrogen containing materials. In the Diablo type (fig. 25) the normal soil was about midway in its production as compared with the soils to which the nitrogenous materials were added. In the Hanford fine sandy loam the normal soils gave a much lower percentage nitrification than in the greater number of instances where the soils were treated with nitrogenous materials. (2) The relative nitrification of the various nitrogenous materials is somewhat distinct for the types. The Diablo, Altamont, and San Joaquin show the ammonium sulfate first, with the cottonseed meal second, and the dried blood third. The Hanford type shows cottonseed meal first, with dried blood second and ammonium sulfate third.

TABLE 37—NITRIFICATION

Diablo Clay Adobe

Sample	Soil nitrogen			Soil nitrogen and ammonium sulfate			Soil nitrogen and dried blood			Soil nitrogen and cottonseed meal		
	Nitrate produced, mg.	Total N present in soil, mg.	Nitrogen nitrified, %	Nitrate produced, mg.	Total N present in soil, mg.	Nitrogen nitrified, %	Nitrate produced, mg.	Total N present in soil, mg.	Nitrogen nitrified, %	Nitrate produced, mg.	Total N present in soil, mg.	Nitrogen nitrified, %
1–A	0.90	104.43	0.86	5.35	146.82	3.65	2.20	347.22	0.63	5.00	198.42	2.50
1–B	0.28	93.34	0.30	0.77	135.74	0.57	Tr.	336.14	......	Tr.	187.34	......
1–C	0.19	57.22	0.33	0.25	99.62	0.25	0.07	300.02	0.02	0.16	151.22	......
2–A	0.47	91.76	0.51	3.47	134.16	2.58	4.07	334.56	1.22	6.82	185.76	3.77
2–B	0.33	67.60	0.49	1.17	110.00	1.06	0.08	310.40	......	0.19	161.60	0.12
2–C	0.59	59.54	......	0.29	101.94	......	0.80	302.34	......	0.80	153.54	......
5–A	0.47	83.82	0.56	3.81	126.22	3.02	1.66	326.62	0.51	3.76	177.82	2.12
5–B	0.36	64.78	0.56	0.42	107.18	0.39	0.19	307.58	0.06	0.97	158.78	0.61
6–A	0.59	116.58	0.51	4.58	158.98	2.88	3.13	359.38	0.87	6.88	210.58	3.26
6–B	1.65	101.54	1.63	3.00	143.94	2.08	1.19	344.34	0.35	4.55	195.54	2.32
6–C	0.96	78.10	1.23	1.01	120.50	0.84	0.37	320.90	0.01	0.47	172.10	0.27
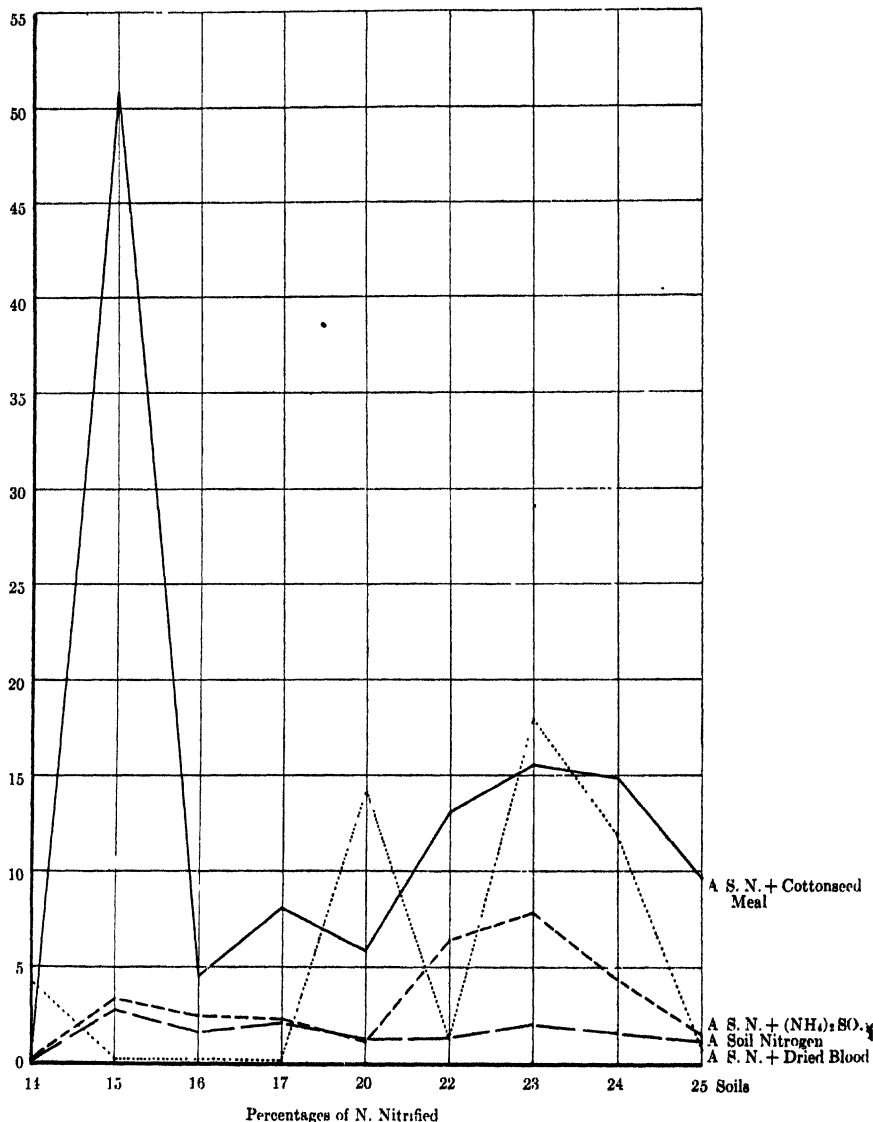
Fig. 26. Graph showing the percentages of nitrogen in various nitrogen containing materials nitrified in the nine samples of the Hanford fine sandy loam.

TABLE 38—NITRIFICATION—·PERCENTAGES OF NITROGEN NITRIFIED

Diablo Clay Adobe

Sample	Soil nitrogen			Soil nitrogen and ammonium sulfate			Soil nitrogen and dried blood			Soil nitrogen cottonseed meal		
	A	B	C	A	B	C	A	B	C	A	B	C
1	0.86	0.30	0.33	3.65	0.57	0.25	0.63	......	0.02	2.50	......	......
2	0.51	0.49	......	2.58	1.06	......	1.22	......	......	3.77	0.12	......
5	0.56	0.56	......	3.02	0.39	......	0.51	0.06 ●	......	2.12	0.61	......
6	0.51	1.63	1.23	2.88	2.08	0.84	0.87	0.35	0.01	3.26	2.32	0.27
Average	0.61	0.74	0.52	3.03	1.02	0.36	0.81	0.10	0.01	2.91	0.76	0.09

TABLE 39—NITRIFICATION

Altamont Clay Loam

Sample	Soil nitrogen			Soil nitrogen and ammonium sulfate			Soil nitrogen and dried blood			Soil nitrogen and cottonseed meal		
	Nitrate produced, mg.	Total N present in soil, mg.	Nitrogen nitrified, %	Nitrate produced, mg.	Total N present in soil, mg.	Nitrogen nitrified, %	Nitrate produced, mg	Total N present in soil, mg	Nitrogen, nitrified, %	Nitrate produced, mg	Total N present in soil, mg	Nitrogen, nitrified, %
3–A	0.60	123.42	0.49	4.12	165.82	2.49	1.17	366.22	0.32	3.57	217.42	1.64
3–B	0.04	87.56	0.05	0.39	129.96	0.32	0.18	330.36	......	0.03	181.56	......
3–C	0.27	67.52	0.40	0.20	109.92	0.18	0.10	310.32	......	0.10	161.52	......
4–A	1.30	102.58	1.27	2.95	144.98	2.05	2.34	345.38	0.68	4.83	196.58	2.46
4–B	0.45	52.96	0.85	......	95.36	......	0.10	295.76	......	......	146.96	......
4–C	......	40.96	......	......	83.36	......	......	283.76	......	0.20	134.96	0.15
7–A	0.50	104.24	0.48	1.35	146.64	0.93	0.40	347.04	0.12	1.27	198.24	0.64
7–B	0.25	73.20	0.34	0.32	115.60	0.28	.....	316.00	......	......	167.20	......
7–C	......	59.88	......	......	102.28	......	.....	302.68	......	......	153.88	......

TABLE 40—NITRIFICATION—PERCENTAGES OF NITROGEN NITRIFIED

Altamont Clay Loam

Sample	Soil nitrogen			Soil nitrogen and ammonium sulfate			Soil nitrogen and dried blood			Soil nitrogen and cottonseed meal		
	A	B	C	A	B	C	A	B	C	A	B	C
3	0.49	0.05	0.40	2.49	0.32	0.18	0.32	......	......	1.64	......	......
4	1.27	0.85	......	2.05	......	......	0.68	......	......	2.46	......	0.15
7	0.48	0.34	......	0.93	0.28	......	0.12	......	......	0.64	......	......
Average	0.75	0.41	0.13	1.82	0.20	0.06	0.37	..... .	......	1.58	......	0.05

TABLE 41—NITRIFICATION

San Joaquin Sandy Loam

	Soil nitrogen			Soil nitrogen and ammonium sulfate			Soil nitrogen and dried blood			Soil nitrogen and cottonseed meal		
Sample	Nitrate produced, mg.	Total N present in soil, mg.	Nitrogen nitrified, %	Nitrate produced, mg.	Total N present in soil, mg.	Nitrogen nitrified, %	Nitrate produced, mg.	Total N present in soil, mg.	Nitrogen nitrified, %	Nitrate produced, mg	Total N present in soil, mg	Nitrogen, nitrified, %
10–A	0.52	37.46	1.4	0.24	122.26	0.2	0.06	302.46	0.02	0.10	121.46	0.08
10–B	0.23	27.18	0.9	0.08	111.98	0.07	......	292.18	......	......	111.18	......
10–C	0.07	20.66	0.3	0.06	105.46	0.06	......	285.66	......	0.08	104.66	0.08
11–A	1.25	50.30	2.5	0.50	135.10	0.4	0.27	315.30	0.09	0.95	134.30	0.7
11–B	......	41.56	....	0.02	126.36	......	0.08	306.56	0.03	0.02	125.56	......
11–C	0.14	38.86	0.4	Tr.	123.66	......	Tr.	303.86	......	Tr.	122.86	......
12–A	0.80	46.52	1.7	0.55	131.32	0.4	0.09	311.52	0.03	2.05	130.52	1.6
12–B	0.18	33.12	0.5	0.11	117.92	0.09	Tr.	298.12	......	Tr.	117.12	......
12–C	0.14	40.82	0.3	0.06	125.62	......	0.06	305.82	......	0.06	124.82	......
13–A	0.49	40.00	1.2	0.59	124.80	0.5	0.07	305.00	0.02	0.10	124.00	0.08
13–B	0.06	40.41	. ..	0.10	125.21	0.08	0.21	305.41	......	0.69	124.41	......
13–C	0.35	32.70	1.1	0.25	117.50	0.2	0.00	297.70	......	0.96	116.70	......
17–A	0.54	28.92	1.9	0.45	113.72	0.4	Tr.	293.92	......	......	112.92	......
17–B	......	18.42	....	......	103.22	......	Tr.	283.43	......	0.08	102.42	0.08
18–A	1.25	27.46	4.5	1.00	112.26	0.9	. ....	292.46	......	Tr.	111.46	......
18–B	Tr.	16.18	....	Tr.	100.98	......	Tr.	281.18	......	Tr.	100.18	......
18–C	......	19.48	....	0.10	104.28	1.0	......	284.48	......	......	103.48	......
21–A	1.25	29.00	4.3	1.30	113.80	1.1	Tr.	294.00	......	0.13	113.00	......
21–B	......	11.92	....	......	96.72	......	......	276.92	......	......	95.92	......
21–C	0.01	14.02	....	0.01	98.82	0.01	0.15	279.02	......	0.15	98.02	......
26–A	0.95	40.68	2.3	0.80	125.48	0.6	Tr.	305.68	......	0.19	124.68	0.10
26–B	Tr.	26.28	....	......	111.48	......	Tr.	291.68	. ....	Tr.	110.68	......
26–C	......	16.48	....	......	101.28	......	Tr.	281.48	......	......	100.48	......

TABLE 42—NITRIFICATION—PERCENTAGES OF NITROGEN NITRIFIED

San Joaquin Sandy Loam

Sample	Soil nitrogen			Soil nitrogen and ammonium sulfate			Soil nitrogen and dried blood			Soil nitrogen and cottonseed meal		
	A	B	C	A	B	C	A	B	C	A	B	C
10	1.4	0.9	0.3	0.2	0.07	0.06	0.02	......	......	0.08	......	0.08
11	2.5	....	0.4	0.4	......	......	0.09	0.03	......	0.7	......	......
12	1.7	0.5	0.3	0.4	0.09	......	0.03	......	......	1.6	......	......
13	1.2	....	1.1	0.5	0.08	0.20	0.02	......	......	0.08	......	......
17	1.9	....	....	0.4	......	......	......	......	......	......	0.08	......
18	4.5	....	....	0.9	......	1.00	......	......	......	......	......	......
21	4.3	....	....	1.1	......	0.01	......	......	......	0.10	......	......
26	2.3	....	....	0.6	......	......	......	......	......	0.1	......	......
Average	2.47	0.17	0.3	0.56	0.03	0.18	0.02	......	......	0.33	0.01	0.01

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TABLE 43—NITRIFICATION

Hanford Fine Sandy Loam

</div>

Sample	Soil nitrogen			Soil nitrogen and ammonium sulfate			Soil nitrogen and dried blood			Soil nitrogen and cottonseed meal		
	Nitrate produced, mg.	Total N present in soil, mg.	Nitrogen nitrified, %	Nitrate produced, mg.	Total N present in soil, mg.	Nitrogen nitrified, %	Nitrate produced, mg.	Total N present in soil, mg.	Nitrogen nitrified, %	Nitrate produced, mg	Total N present in soil, mg	Nitrogen, nitrified, %
14–A	0.20	119.22	....	0.25	161.62	0.1	10.35	254.22	4.1	1.85	166.22	1.1
14–B	0.45	82.02	....	0.42	124.42	....	0.23	217.02	....	0.48	129.02	....
14–C	0.07	58.14	0.1	0.75	100.54	0.7	0.15	193.14	0.1	0.10	105.14	0.1
15–A	1.45	53.10	2.7	3.20	95.50	3.4	0.40	188.10	0.2	50.85	100.10	50.8
15–B	0.18	40.24	0.4	0.19	82.64	0.2	Tr.	175.24	....	1.42	87.24	1.6
15–C	0.03	27.74	0.1	0.01	70.14	....	Tr.	162.74	....	0.03	74.74	....
16–A	0.87	55.68	1.6	2.50	98.08	2.5	0.50	190.68	0.2	4.60	102.68	4.5
16–B	0.11	29.70	0.4	0.08	72.10	0.1	Tr.	164.70	....	3.70	76.70	4.8
16–C	0.03	21.22	0.1	Tr.	63.62	....	0.05	156.22	....	0.17	68.22	0.2
19–A	1.00	44.98	2.2	2.03	87.38	2.3	0.21	179.98	0.1	7.48	91.98	8.1
19–B	0.08	24.58	0.3	0.12	66.98	0.2	......	159.58	....	0.20	71.58	0.3
19–C	0.16	23.60	0.7	0.15	66.00	0.2	Tr.	158.60	....	0.20	70.60	0.3
20–A	0.77	59.32	1.3	1.24	101.72	1.2	27.39	194.32	14.1	6.19	104.32	5.9
20–B	0.12	32.78	0.4	0.11	75.18	0.1	15.50	167.78	9.2	1.45	77.78	1.9
20–C	......	23.04	. ..	......	65.44	....	....	158.04	....	0.07	68.04	0.1
22–A	0.83	58.34	1.4	6.48	100.74	6.4	2.68	193.34	1.4	13.58	.103.34	13.1
22–B	0.27	34.46	0.8	0.26	76.86	0.3	0.04	169.46	0.02	1.91	79.46	2.4
22–C	0.85	23.74	3.6	5.40	66.14	8.2	0.52	158.74	0.3	2.50	68.74	3.6
23–A	1.45	72.20	2.0	8.95	114.6	7.8	37.25	207.20	17.9	18.25	117.20	15.5
23–B	0.75	29.14	2.6	8.90	71.54	12.5	0.47	164.14	0.3	2.65	74.14	3.6
23–C	0.32	17.80	1.8	12.40	60.20	20.6	0.02	152.80	0.01	1.30	62.80	2.1
24–A	0.80	51.34	1.6	4.10	93.74	4.4	22.35	186.34	11.9	14.35	96.34	14.9
24–B	0.03	33.90	0.1	0.36	76.30	0.5	0.46	168.90	0.3	5.91	78.90	7.5
24–C	0.33	27.82	1.1	0.33	70.22	0.5	0.63	162.82	0.4	0.73	72.82	1.0
25–A	0.56	45.40	1.2	1.30	87.80	1.5	1.30	180.40	0.7	8.65	90.40	9.6
25–B	0.32	31.01	1.0	0.32	73.41	0.4	Tr.	166.01	....	0.05	76.01	0.06
25–C	0.11	22.62	0.5	0.16	65.02	0.2	Tr.	157.62	....	Tr.	67.62	......

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TABLE 44—NITRIFICATION—PERCENTAGES OF NITROGEN NITRIFIED

Hanford Fine Sandy Loam

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Sample	Soil nitrogen			Soil nitrogen and ammonium sulfate			Soil nitrogen and dried blood			Soil nitrogen and cottonseed meal		
	A	B	C	A	B	C	A	B	C	A	B	C
14	....	....	0.1	0.1	....	0.7	4.1	....	0.1	1.1	....	0.1
15	2.7	0.4	0.1	3.4	0.2	....	0.2	....	....	4.5	4.8	0.2
16	1.6	0.4	0.1	2.5	0.1	....	0.2	....	....	4.5	4.8	0.2
19	2.2	0.3	0.7	2.3	0.2	0.2	0.1	....	....	8.1	0.3	0.3
20	1.3	0.4	....	1.2	0.1	....	14.1	9.2	....	5.9	1.9	0.1
22	1.4	0.8	3.6	6.4	0.3	8.2	1.4	0.02	0.3	13.1	2.4	3.6
23	2.0	2.6	1.8	7.8	12.5	20.6	17.9	0.3	0.01	15.5	3.6	2.1
24	1.6	0.1	1.1	4.4	0.5	0.5	11.9	0.3	0.4	14.9	7.5	1.0
25	1.2	1.0	0.5	1.5	0.4	0.2	0.7	....	....	9.6	0.06	....
Average	1.55	0.66	0.88	3.29	1.59	3.38	5.62	1.09	0.09	13.72	2.55	0.82

GREENHOUSE DATA

There are objections to all greenhouse work due to somewhat unnatural conditions for the usual indicator crops, the lack of a normal water supply, the small amount of root space, etc. Crowding of the pots is also apt to cause variations. Even the slight change in the location of a pot on the bench will affect the growth of plants, as some of the elaborate precautions for moving the pots daily, and in a given order, testify. The outstanding advantage of greenhouse work is that with a given indicator crop a group of soils, or soil conditions, may be compared under very similar conditions.

In the present case, the leaks in the sash allowed rain water to fall into some of the pots to a considerable extent. The pots so affected showed a poorer growth in the cases of the heavy Altamont and Diablo samples, where the soil was readily compacted, while in the poor Hanford and San Joaquin soils the pots receiving leakage water showed markedly better growth.

To minimize such errors, as much as possible, triplicates were used, as above explained, besides repeating the series. In working out the final averages of the crop it was suggested that a selection be made of the crop dry weights, in case that there was a marked variation between the triplicates, using the two weights close together, and excluding the third if it were widely divergent. However, when one begins to select certain figures from a series, and bases comparisons upon these alone, there is apt to be the tendency to select those figures that will prove the point in question, unless there is some known disturbing factor causing the divergence and which warrants the exclusion of certain figures.

Other cases that are rather hard to deal with are those in which the number of plants reaching maturity was not up to the standard to which the series was thinned when the plants were young. This failure may have been due to poor germination, or to accidental destruction of the plants during growth. Sometimes less than the standard number of plants will give a much greater dry weight per plant than the normal number. It was not deemed advisable to use the weight per plant, but rather to use the total dry weight of the crop, and only consider of value the series in which the number of plants per pot was practically constant.

In the greenhouse work the Diablo clay adobe, the Altamont clay loam, and the Hanford fine sandy loam samples were compared by

two croppings, while one crop was grown on the San Joaquin sandy loam soils. The infertility of the San Joaquin soils, in some cases extreme, greatly retarded crop growth.

Diablo clay adobe. First crop.—Due to the presence of wild oat seed in all the four samples of this soil, and the inability to distinguish the young wild oat plants from the planted oats, wheat, or barley when thinning, the value of the results of the grain crops in this series is much decreased. The averages plotted include the total
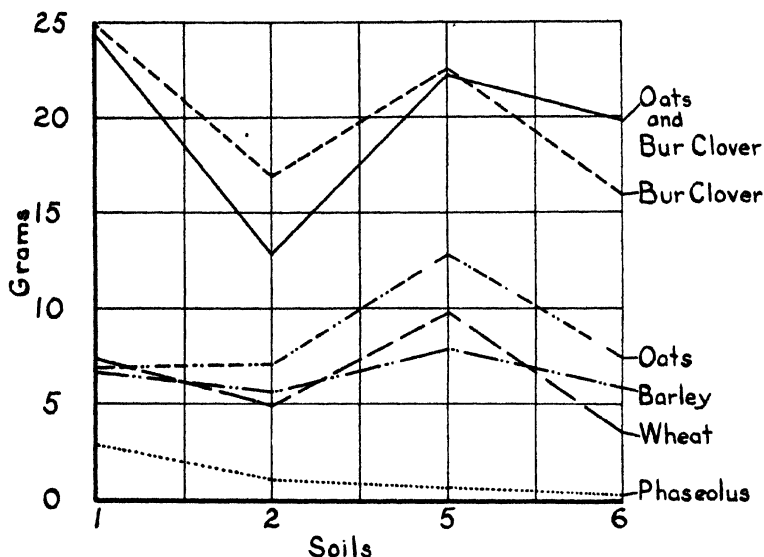
Fig. 27. Graph showing the total dry matter produced by wheat, barley, oats, *Phaseolus*, bur clover, and oats and bur clover on the four samples of Diablo clay adobe. First crop.

crop, whether pure or with a greater or less quantity of the wild oats, though the number of plants harvested was usually six or less. Planting the oats and bur clover together was not a success. In three of the soils the crop of bur clover alone was greater than that of the six bur clover plants plus the six oat plants. Plate 44 shows how, in some cases, the oats dominated, and in others the bur clover was superior. On the soils of this type bur clover was the most satisfactory crop, while the white beans were the most unsatisfactory of all.

Comparing the total crops (see fig. 27 and tables 45–50), it will be seen that 1, 5, 2, 6 is the order for bur clover, soil no. 1 giving the

best crop and soil no. 6 the poorest, while nos. 5, 1, 2, 6 is the order for barley and wheat. Oats show nearly double the crop on soil 5 that it does on any of the other three soils. There is thus a general agreement between the indicators that the soils are not of the same productivity.

TABLE 45—DIABLO CLAY ADOBE, FIRST CROP

WHEAT

Planted, November 6, 1915. Harvested, July 10, 1916

Pot	No. plants	Straw		Grain		Total dry matter		Notes
		Weight	Average weight	Weight	Average weight	Weight	Average weight	
1–1	Wheat 2	3.65		0.25			·	
	Oats 4	2.15		0.69		6.74		
1–2	Wheat 0	....		....				
	Oats 6	4.05		2.47		6.51		
1–3	Wheat 1	1.83		....		·		
	Oats 5	5.20	5.62	1.64	1.68	8.66	7.30	
2–1	Wheat 5	5.33		0.05				
	Oats 1	0.43		....		5.81		
2–2	Wheat 4	3.53		0.03				
	Oats 2	0.69		0.04		4.31		
2–3	Wheat 3	2.55		....				
	Oats 3	1.39	4.63	0.49	0.21	4.43	0.84	
5–1	Wheat 2	4.33		0.90				
	Oats 4	1.56		0.42		7.21		
5–2	Wheat 3	7.28		1.81				
	Oats 2	3.23		1.02		13.44		
5–3	Wheat 3	7.09		0.48				
	Oats 2	0.64	8.04	0.47	1.70	8.68	9.74	
6–1	Wheat 2	2.19		....				
	Oats 4	1.03		....		3.22		
6–2	Wheat 0	....		....				
	Oats 5	1.72		....		1.72		
6–3	Wheat 2	2.31		....				
	Oats 4	2.51	3.25	0.70	0.17	5.53	3.49	

TABLE 46—DIABLO CLAY ADOBE, FIRST CROP

BARLEY

Planted, November 6, 1915. Harvested, April 28, 1916

Pot	No. plants	Straw Weight	Straw Average weight	Grain Weight	Grain Average weight	Total dry matter Weight	Total dry matter Average weight	Notes
1–1	6	5.19		1.06		6.25		
1–2	Barley 5	4.79		0.75				
	Oats 1	......		......		5.54		
1–3	Barley 4	5.75		1.34				
	Oats 2	......	5.24	0.98	1.38	8.07	6.62	
2–1	6	5.12		1.05		6.17		
2–2	6	4.87		1.71		6.58		
2–3	Barley 5	2.78		0.49				
	Oats 1	0.69	4.49	0.23	1.16	4.19	5.65	
5–1	6	6.59		2.12		8.70		
5–2	Barley 5			3.01				
	Oats 1	2.56		0.25		3.25		
5–3	Barley 5			3.01				
	Oats 1	8.43	5.86	0.04	1.95	11.48	7.81	
6–1	6	4.62		1.26		5.88		
6–2	6	4.36		1.25		5.61		
6–3	Barley 5			0.33				
	Oats 1	3.49	4.16	0.24	1.02	4.06	5.18	

TABLE 47—DIABLO CLAY ADOBE, FIRST CROP

OATS

Planted, November 6, 1915. Harvested, May 8, 1916

Pot	No. plants	Straw Weight	Straw Average weight	Grain Weight	Grain Average weight	Total dry matter Weight	Total dry matter Average weight	Notes
1–1	6	4.11		1.24		5.35		
1–2	6	6.56		2.59		9.15		
1–3	6	4.76	5.14	1.34	1.72	6.10	6.86	
2–1	6	4.36		1.10		5.46		
2–2	6	total only		total only		6.92		
2–3	6	6.66	5.51	2.06	1.58	8.72	7.03	
5–1	7	7.55		2.59		10.15		
5–2	6	10.66		4.38		15.04		One barley plant
5–3	6	10.10		3.12		13.22		
6–1	6	4.70		1.48		6.18		
6–2	6	6.81		1.42		8.22		
6–3	6	6.78		1.09		7.88		

TABLE 48—DIABLO CLAY ADOBE, FIRST CROP

BUR CLOVER

Planted, November 6, 1915.   Harvested, May 8, 1916

Pot	No. plants	Straw		Grain		Total dry matter		Notes
		Weight	Average weight	Weight	Average weight	Weight	Average weight	
1–1	5	11.01		15.13		26.32		
1–2	4	9.07		14.15		23.22		
1–3	6	12.18	10.75	13.02	14.16	25.20	24.91	
2–1	6	8.26		9.89		18.16		
2–2	5	7.45		8.93		16.39		
2–3	6	7.97	7.89	8.02	8.98	15.99	16.84	
5–1	7	11.14		12.33		23.48		
5–2	8	10.67		13.05		23.72		
5–3	7	10.55	10.79	9.76	11.71	20.31	22.50	
6–1	6	7.96		8.73		16.69		
6–2	6	8.26		9.76		18.02		
6–3	6	6.87	7.69	6.04	8.18	12.91	15.87	

TABLE 49—DIABLO CLAY ADOBE, FIRST CROP

OATS AND BUR CLOVER

Planted, November 6, 1915.   Harvested, May 8, 1916

Pot	No. plants	Straw		Grain		Total dry matter		Notes
		Weight	Average weight	Weight	Average weight	Weight	Average weight	
1–1	Clover 3	10.37		11.93		22.30		
	Oats 6	2.38		0.14		2.52		
1–2	Clover 6	8.19		9.28		17.47		
	Oats 6	3.48		0.70		4.16		
1–3	Clover 6 ·	13.53		9.81		23.34		
	Oats 6	2.65	13.53	0.27	10.71	2.92	24.24	
2–1	Clover 6	2.13		2.57		4.70		
	Oats 6	5.77		1.81		7.58		
2–2	Clover 6	4.24		4.62		8.87		
	Oats 6	4.56		1.26		5.82		
2–3	Clover 6	3.43		4.51		7.94		
	Oats 6	3.20	7.75	0.46	5.08	3.66	12.85	
5–1	Clover 6	10.88		9.78		20.66		
	Oats 6	2.45		0.27		2.71		
5–2	Clover 5	10.52		9.32		19.84		
	Oats 6	2.19		0.51		2.79		
5–3	Clover 5	8.31		8.36		16.66		
	Oats 6	3.45	12.60	0.66	9.63	4.10	22.26	
6–1	Clover 6	8.90		9.56		18.46		
	Oats 6	3.10		0.35		3.45		
6–2	Clover 6	9.01		5.82		14.83		
	Oats 6	2.09		0.52		2.61		
6–3	Clover 6	6.51		10.45		16.97		
	Oats 5	2.33	10.65	0.47	9.06	2.80	19.71	

TABLE 50—DIABLO CLAY ADOBE, FIRST CROP

Phaseolus vulgaris

Planted, April 4, 1916.   Harvested, October 7, 1916

Pot	No. plants	Straw Weight	Straw Average weight	Grain Weight	Grain Average weight	Total dry matter Weight	Total dry matter Average weight	Notes
1–1	8	2.05		0.58		2.63		Growth poor and
1–2	1	0.94		0.87		1.81		slow through-
1–3	12	2.86	1.95	1.37	0.94	4.23	2.89	out
2–1	3	0.53		0.21		0.74		
2–2	10	0.83		......		0.83		
2–3	17	1.26	0.87	0.11	0.10	1.37	0.98	
5–1	3	0.53		0.40		0.93		
5–2	2	0.46		0.41		0.87	'	
5–3	....	......	0.33	......	0.27	......	0.60	
6–1	2	0.22		......		0.22		
6–2	....	......		......		......		
6–3	1	0.23	0.15	......	......	0.23	0.15	

Diablo clay adobe. Second crop.—The crops used in this plant-
ing were milo (two series, one following oats and bur clover, and the
other following oats alone), cowpeas, millet, and soy beans. The
crop was thinned as follows: milo to eight plants, millet to twelve,
soy beans to six, and cowpeas to six. The total dry weight (tables
51–55) of the largest leguminous crop in this planting is about one-
third of that of the bur clover in the first planting; though the grains
are proportionately not nearly so much less than in the first crop.
Soil no. 2 has the least pronounced adobe structure, but was the most
easily puddled. The plants in one of the pots of soy beans of soil
no. 2 were entirely killed by too much water.

Comparing the relative growth on the soils, the notes made while
the crops were growing coincide very closely with the dry weights.
As to the relative crop production (fig. 28), it can be said that soils
nos. 1 and 5 produced larger crops than soils nos. 2 and 6. Thus the
second crop results substantiate those of the first crop.
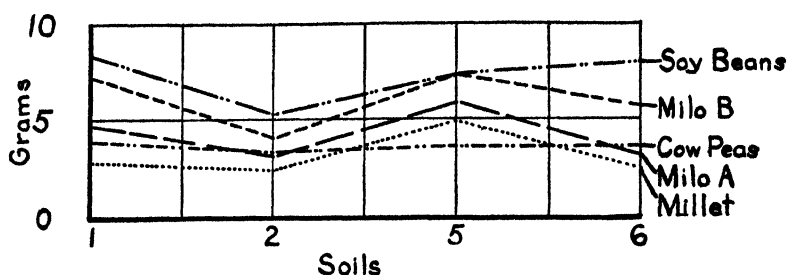
Fig. 28. Graph showing the total dry matter produced by milo (two series), millet, soy beans, and cowpeas on the four samples of Diablo clay adobe. Second crop.
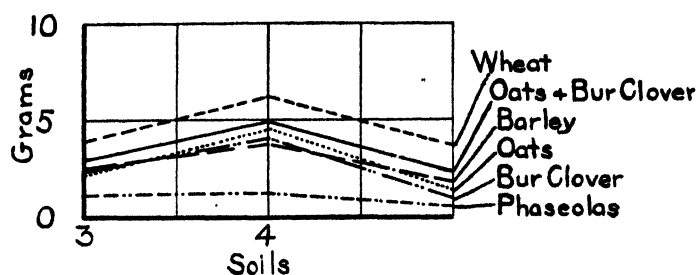
Fig. 29. Graph showing the total dry matter produced by wheat, barley, oats, bur clover, *Phaseolus,* and oats and bur clover on the three samples of Altamont clay loam. First crop.
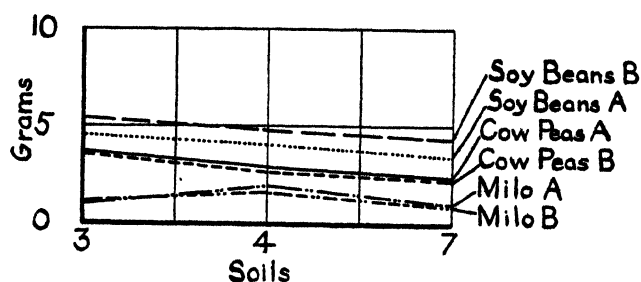
Fig. 30. Graph showing the total dry matter produced by milo (two series), cowpeas (two series), and soy beans (two series) on the three samples of Altamont clay loam. Second crop.

TABLE 51—DIABLO CLAY ADOBE, SECOND CROP

MILO A (following oats)

Planted, June 3, 1916.   Harvested, November 16, 1916

Pot	No. plants	Straw		Grain		Total dry matter		Notes
		Weight	Average weight	Weight	Average weight	Weight	Average weight	
1–1	8	4.87		......		4.87		Excluded from
1–2	8	10.00		......		10.00		average
1–3	7	4.50	4.68	......	......	4.50	4.68	
2–1	8	2.59		......		2.59		
2–2	8	3.73		......		3.73		
2–3	8	2.92	3.08	......	......	2.92	3.08	
5–1	8	4.03		......		4.03		
5–2	6	5.13		......		5.13		
5–3	7	8.44		......		8.44		
6–1	9	3.49		......		3.49		
6–2	8	3.08		......		3.08		
6–3	8	2.98	3.18	......	......	2.98	3.18	

TABLE 52—DIABLO CLAY ADOBE, SECOND CROP

MILO B (following oats and bur clover)

Planted, June 3, 1916.   Harvested, November 16, 1916

Pot	No. plants	Straw		Grain		Total dry matter		Notes
		Weight	Average weight	Weight	Average weight	Weight	Average weight	
1–1	8	6.41		......		6.41		
1–2	8	8.78		......		8.78		
1–3	8	6.21	7.14	......	......	6.21	7.14	
2–1	8	3.92		......		3.92		
2–2	8	4.52		......		4.52		
2–3	8	3.63	4.02	......	......	3.63	4.02	
5–1	8	10.34		......		10.34		
5–2	8	6.17		......		6.17		
5–3	8	5.20	7.24	......	......	5.20	7.24	
6–1	8	9.29		......		9.29		
6–2	8	3.70		......		3.70		
6–3	8	4.09	5.69	......	......	4.09	5.69	

TABLE 53—DIABLO CLAY ADOBE, SECOND CROP

MILLET (following bur clover)

Planted, June 3, 1916.   Harvested, October 6, 1917

Pot	No. plants	Straw		Grain		Total dry matter		Notes
		Weight	Average weight	Weight	Average weight	Weight	Average weight	
1–1	12	1.52		1.44		2.96		
1–2	11	1.34		0.90		2.24		
1–3	11	2.03	1.63	1.15	1.16	3.18	2.79	.
2–1	12	1.26		1.29		2.55		
2–2	11	1.49		1.32		2.80		
2–3	12	0.93	1.23	0.88	1.16	1.80	2.39	
5–1	10	2.26		2.19		4.45		.
5–2	12	3.35		3.36		6.71		
5–3	12	2.02	2.54	1.51	2.35	3.53	4.90	
6–1	11	1.19		0.99		2.18		
6–2	12	1.59		1.23		2.82 .		
6–3	13	1.26	1.35	1.04	1.09	2.29	2.43	

TABLE 54—DIABLO CLAY ADOBE, SECOND CROP

COWPEAS (following wheat)

Planted, August 10, 1916.   Harvested, November 16, 1916

Pot	No. plants	Straw		Grain		Total dry matter		Notes
		Weight	Average weight	Weight	Average weight	Weight	Average weight	
1–1	7	2.66		......		2.66		
1–2	7	5.30		......		5.30		
1–3	7	3.73	3.89	......	......	3.73	3.89	
2–1	6	2.57		......		2.57		
2–2	6	4.24		......		4.24		
2–3	6	2.86	3.22	......	......	2.86	3.22	
5–1	6	2.74		......		2.74		
5–2	6	4.30		......		4.30		
5–3	6	3.64	3.56	......	......	3.64	3.56	
6–1	6	3.28		......		3.28		
6–2	7	4.10		......		4.10		
6–3	6	3.41	3.60	......	......	3.41	3.60	

TABLE 55—DIABLO CLAY ADOBE, SECOND CROP
SOY BEANS (following barley)
Planted, June 6, 1916. Harvested, November 14, 1916

| Pot | No. plants | Straw | | Grain | | Total dry matter | | Notes |
		Weight	Average weight	Weight	Average weight	Weight	Average weight	
1–1	6	8.48		0.29		8.77		
1–2	6	8.58		0.06		8.64		
1–3	6	6.87	7.98	0.41	0.25	7.28	8.23	
2–1	6	2.12		......		2.12		Excluded from
2–2	4	3.62		0.40		4.02		average
2–3	5	6.07	4.84	0.38	0.39	6.45	5.23	.
5–1	6	5.84		0.16		6.00		
5–2	6	7.96		0.64		8.60		
5–3	6	6.47	6.76	0.69	0.49	7.16	7.25	
6–1	6	7.61		0.24		7.85		
6–2	6	7.99		0.45		8.43		
6–3	6	7.26	7.62	0.17	0.28	7.43	7.90	

Altamont clay loam. First crop.—The crops planted in this soil were wheat, barley, oats, bur clover, *Phaseolus*, and oats and bur clover together. The standard number to which the plants were thinned was six, except in the oats and bur clover series, where three plants of each were allowed to remain.

With regard to the comparative crop producing power of these soils under these conditions, soil no. 4 is the best, with soil no. 3 as the second, and soil no. 7 was the poorest (tables 56–60, fig. 29). The dry weight data decidedly corroborate the impression given by the greenhouse appearance of the crops. However, as all the crops were so small on all the series, the figures do not show as much as they might have shown had the growth been more nearly optimum for the several crops.

TABLE 56—ALTAMONT CLAY LOAM, FIRST CROP
WHEAT
Planted, February 25, 1916. Harvested, July 10, 1916

| Pot | No. plants | Straw | | Grain | | Total dry matter | | Notes |
		Weight	Average weight	Weight	Average weight	Weight	Average weight	
3–1	6	2.62		1.23		3.85		
3–2	6	2.93		1.09		3.92		
3–3	6	2.86	2.80	1.04	1.12	3.91	3.92	
4–1	6	4.20		1.78		5.97		
4–2	6	4.03		1.22		5.25		
4–3	6	6.20	4.81	1.13	1.38	7.34	6.19	
7–1	6	2.64		1.11		3.76		
7–2	6	2.58		0.99		3.64		
7–3	6	2.90	2.71	0.71	0.93	3.61	3.64	

TABLE 57—ALTAMONT CLAY LOAM, FIRST CROP

BARLEY

Planted, April 4, 1916. Harvested, July 11, 1916

Pot	No. plants	Straw		Grain		Total dry matter		Notes
		Weight	Average weight	Weight	Average weight	Weight	Average weight	
3–1	....	1.10		0.76		1.86		
3–2	....	1.45		1.40		2.85		
3–3	....	1.39	1.31	1.18	1.11	2.57	2.43	
4–1	....	1.99		1.43		3.42		
4–2	....	1.90		1.57		3.47		
4–3	....	2.39	2.09	1.85	1.62	4.25	3.71	
7–1	....	0.98		0.90		1.88		
7–3	....	1.06	1.00	0.59	0.71	1.64	1.71	

TABLE 58—ALTAMONT CLAY LOAM, FIRST CROP

OATS

Planted, February 25, 1916. Harvested July 11, 1916

Pot	No. plants	Straw		Grain		Total dry matter		Notes
		Weight	Average weight	Weight	Average weight	Weight	Average weight	
3–1	6	1.36		0.38		1.74		
3–2	6	1.60		0.67		2.27		
3–3	6	1.70	1.55	0.47	0.51	2.17	2.06	
4–1	6	3.05		1.42		4.47		
4–2	4	2.62		1.13		3.76		
4–3	4	3.46	3.04	1.81	1.45	5.27	4.50	
7–1	6	1.21		0.29		1.51		
7–2	6	1.00		0.42		1.42		
7–3	6	0.88	1.03	0.35	0.35	1.23	1.38	

TABLE 58—ALTAMONT CLAY LOAM, FIRST CROP

BUR CLOVER

Planted, February 25, 1916. Harvested, July 8, 1916

Pot	No. plants	Straw		Grain		Total dry matter		Notes
		Weight	Average weight	Weight	Average weight	Weight	Average weight	
3–1	6	1.50		1.03		2.53		
3–2	6	0.88		1.17		2.18		
3–3	6	0.63	1.00	1.34	1.18	1.96	2.18	
4–1	6	2.48		1.47		3.95		
4–2	6	2.57		1.57		4.14		
4–3	4	2.50	2.52	1.31	1.45	3.81	3.97	
7–1	6	0.47		0.66		1.13		
7–2	6	0.53		0.24		0.78		
7–3	6	0.37	0.46	0.20	0.36	0.57	0.82	

TABLE 59—ALTAMONT CLAY LOAM, FIRST CROP

OATS AND BUR CLOVER

Planted, April 14, 1916. Harvested, July 8, 1916

Pot	No. plants	Straw Weight	Average weight	Grain Weight	Average weight	Total dry matter Weight	Average weight	Notes
3–1	B. C. 3	0.98		1.25		2.23		
	Oats 3	0.77		0.10		0.88		
3–2	B. C. 4	0.79		1.17		1.96		
	Oats 4	0.68		0.22		0.90		
3–3	B. C. 4	0.48		0.91		1.38		
	Oats 4	0.78	1.49	0.30	1.32	1.07	2.81	
4–1	B. C. 3	0.67		0.32		0.99		
	Oats 3	2.42		1.75		4.17		
4–2	B. C. 3	0.40		0.62		1.01		
	Oats 3	2.63		1.38		4.01		
4–3	B. C. 3	0.51		0.21		0.72		
	Oats 3	2.77	3.14	1.09	1.78	3.86	4.92	
7–1	B. C. 3	0.20		0.27		0.47		
	Oats 3	0.86		0.74		1.60		
7–2	B. C. 3	0.28		0.22		0.50		
	Oats 3	1.27		0.95		2.22		
7–3	B. C. 4	0.42		0.37		0.74		
	Oats 2	0.64	1.22	0.44	0.98	1.08	2.20	

TABLE 60—ALTAMONT CLAY LOAM, FIRST CROP

BEANS (*Phaseolus*)

Planted, February 25, 1916. Harvested, July 11, 1916

Pot	No. plants	Straw Weight	Average weight	Grain Weight	Average weight	Total dry matter Weight	Average weight	Notes
3–1	6	2.82		0.13		2.96		
3–2	6	1.24		0.35		1.59		
3–3	6	1.32	1.79	0.32	0.27	1.64	2.06	
4–1	5	1.71		0.25		1.96		
4–2	6	1.41		0.59		2.01		
4–2	6	1.81	1.64	0.59	0.48	2.41	2.12	
7–1	1	0.11		0.09		0.20		
7–2	6	0.53		......		0.53		
7–3	5	0.63	0.43	......	0.03	0.63	0.46	

Altamont clay loam. Second crop.—A slightly different scheme was used in the planting of this series, only three crops were used, i.e., soy beans, cowpeas, and milo. Two sets of pots were planted to each crop, one of the two sets having previously been planted to a legume, and the other to a non-legume. The milo was thinned so that

one pot of each triplicate set would have 8 plants, the second of the set 12 plants, and the last 16 plants. It was found that the wide variation in the number of plants had but little effect upon the dry weight produced per pot (tables 61–66). The effect was indeed so slight that the totals were averaged up as usual. Figure 30 shows distinctly that there was very little variation as regards total production among these soils, so little as not to warrant any conclusions as regards substantiation of, or disagreement with, the first crop. It will be noticed in the second crop of the Diablo series, as well as in that of the Altamont series, that the maintenance of the soils under the same conditions for a year or more seems to bring them quite rapidly to an average crop producing power.

TABLE 61—ALTAMONT CLAY LOAM, SECOND CROP

MILO A (following wheat)

Planted, August 10, 1916. Harvested, November 17, 1916

Pot	No. plants	Straw		Grain		Total dry matter		Notes
		Weight	Average weight	Weight	Average weight	Weight	Average weight	
3–1	8	0.77		....		0.77		
3–2	12	1.01		....		1.01		
3–3	16	0.97	0.92	....	....	0.97	0.92	
4–1	8	1.22		....		1.22 ·		
4–2	12	2.32		....		2.32		
4–3	16	2.08	1.87	....	....	2.08	1.87	
7–1	8	0.59		....		0.59		
7–2	12	0.99		....		1.29		
7–3	16	1.29	0.95	....	....	1.29	0.95	

TABLE 62—ALTAMONT CLAY LOAM, SECOND CROP

MILO B

Planted, August 10, 1916. Harvested, November 15, 1916

Pot	No. plants	Straw		Grain		Total dry matter		Notes
		Weight	Average weight	Weight	Average weight	Weight	Average weight	
3–1	8	0.82		....		0.82		
3–2	12	1.13		....		1.13		
3–3	16	1.15	1.03	....	....	1.15	1.03	
4–1	8	1.28		....		1.28		
4–2	12	1.82		....		1.82		
4–3	16	1.45	1.52	....	....	1.45	1.52	
7–1	8	0.66		....		0.66		
7–2	12	0.96		....		0.96		
7–3	16	0.92	0.85	....	....	0.92	0.85	

TABLE 63—ALTAMONT CLAY LOAM, SECOND CROP

COWPEAS A (following barley)

Planted, August 10, 1916. Harvested, November 17, 1916

Pot	No. plants	Straw		Grain		Total dry matter		Notes
		Weight	Average weight	Weight	Average weight	Weight	Average weight	
3–1	6	3.48		....		3.48		
3–2	6	4.50		....		4.50		
3–3	6	3.00	3.66	....	....	3.00	3.66	
4–1	6	2.44		....		2.44		
4–2	6	2.59		....		2.59		
4–3	6	3.40	2.81	....	....	3.40	2.81	
7–1	6	2.64		....		2.64		
7–2	6	1.93		....		1.93		
7–3	6	2.15	2.24	....	....	2.15	2.24	

TABLE 64—ALTAMONT CLAY LOAM, SECOND CROP

COWPEAS B (following oats and bur clover)

Planted, August 10, 1916. Harvested, November 14, 1916

Pot	No. plants	Straw		Grain		Total dry matter		Notes
		Weight	Average weight	Weight	Average weight	Weight	Average weight	
3–1	6	4.16		....		4.16		
3–2	6	3.63		....		3.63		
3–2	6	2.77	3.52	....	....	2.77	3.52	
4–1	6	3.35		....		3.35		
4–2	6	2.70		....		2.70		
4–3	6	1.94	2.66	....	....	1.94	2.66	
7–1	6	1.51		....		1.51		
7–2	6	2.10		....		2.10		
7–3	6	2.85	2.15	....	....	2.85	2.15	

TABLE 65—ALTAMONT CLAY LOAM, SECOND CROP

SOY BEANS A (following oats).

Planted, August 10, 1916. Harvested, November 17, 1916

Pot	No. plants	Straw		Grain		Total dry matter		Notes
		Weight	Average weight	Weight	Average weight	Weight	Average weight	
3–1	6	4.85		....		4.85		
3–2	6	4.25		....		4.25		
3–3	6	4.50	4.53	....	....	4.50	4.53	
4–1	6	3.53		....		3.53		
4–2	6	3.59		....		3.59		
4–3	6	4.88	4.00	....	....	4.88	4.00	
7–1	6	3.42		....		3.42		
7–2	6	3.34		....		3.34		
7–3	6	3.42	3.39	....	....	3.42	3.39	

TABLE 66—ALTAMONT CLAY LOAM, SECOND CROP

SOY BEANS (following *Phaseolus*)

Planted, August 10, 1916. Harvested November 17, 1916

		Straw		Grain		Total dry matter		
Pot	No. plants	Weight	Average weight	Weight	Average weight	Weight	Average weight	Notes
3–1	6	5.64		......		5.64		
3–2	6	4.94		......		4.94		
3–3	6	4.84	5.14	......	......	4.84	5.14	
4–1	6	4.74		......		4.74		
4–2	6	4.64		......		4.64		
4–3	6	4.71	4.70	..... .	......	4.71	4.70	
7–1	6	5.25		......		5.25		
7–2	6	3.28		......		3.28		
7–3	6	4.39	4.31	......	......	4.39	4.31	

Hanford fine sandy loam.   First crop.—This soil type, with samples from nine different localities in California, gave a much wider range of conditions and made a much more interesting series.   The plants used as indicators in this series were milo (twice), millet, cowpeas (twice), and soy beans.   The milo was thinned to eight plants per pot,·the millet to twelve plants, and the cowpeas and soy beans to six plants.   Set A of cowpeas, and set B of milo were unfavorably located, so that the results of these sets should be discounted.

It is interesting to note the large differences in the average weights from soil to soil (tables 67–72, and fig. 31), as compared with the photographs, in which little variation appears.   See especially the soy bean series.   In this series two things are to be noted:

1. Averages on soils nos. 15 and 25 are hardly representative because in both cases excess moisture, from a leaky roof and too heavy watering, depressed growth.   The tendency to become compact and to remain wet and cold shown by soil no. 15 aided the milo and depressed the soy beans.

2. The loose, open texture of soil no. 22 seemingly favored the soy bean growth, though the other plants did not do as well on this soil as on most of the others.

Comparing the more satisfactory grains, milo A and millet, it will be seen that there is somewhat of a parallelism from soil to soil. The legumes do not always respond similarly to the grains, as in the Diablo first crop, yet in the Diablo second crop and the Altamont first and second crops the response of grain and legume seems quite similar. Hence, it is not safe in every case to judge as to the relationships shown by legumes and non-legumes.
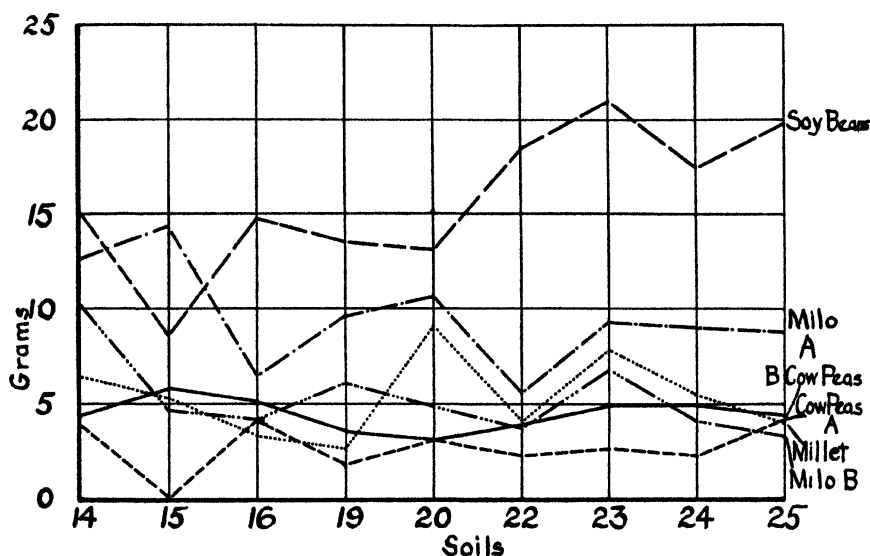
Fig. 31

Fig. 31. Graph showing the total dry matter produced by millet, milo (two series), cowpeas (two series), and soy beans on the nine samples of Hanford fine sandy loam. First crop.

Considering all the variations, one might say that soil no. 23 was seemingly among the better soils, and soils nos. 16 and 22 among the poorer soils. Yet when discussing whether the soils be the same or similar, according to the criterion of the dry weight, one of the Hanford groups will be similar according to one crop, and an overlapping group similar according to the second crop. It can be said with reasonable certainty that these Hanford soils are not closely similar to one another.

TABLE 67—HANFORD FINE SANDY LOAM, FIRST CROP

MILO A

Planted, June 10, 1916.   Harvested, November 18, 1916

		Straw		Grain		Total dry matter		
Pot	No. plants	Weight	Average weight	Weight	Average weight	Weight	Average weight	Notes
14–1	8	15.34		......		15.34		Most plants bore
14–2	8	12.50		......		12.50		no grain; some
14–3	8	10.15	12.66	......	......	10.15	12.66	grain was im-
								mature at har-
								vest. T h e s e
								cases n o t e d,
								but no grain
								weighed.
15–1	8	13.14		......		13.14		
15–2	8	14.50		......		14.50		
15–3	5	15.21	14.28	......	......	15.21	14.28	Not mature
16–1	8	8.67		......		8.67		
16–2	8	5.86		......		5.86		
16–3	8	4.76	6.43	......	......	4.76	6.43	
19–1	8	7.65		......		7.65		
19–2	8	14.11		......		14.11		
19–3	8	7.01		......		7.01		
20–1	8	14.10		......		14.10		
20–2	8	10.15		......		10.15		
20–3	8	7.68	10.64	......	......	7.68	10.64	Not mature
22–1	8	5.34		......		5.34		
22–2	8	5.88		......		5.88		
22–3	8	5.35	5.52	......	......	5.35	5.52	
23–1	8	8.90		......		8.90		Not mature
23–2	8	10.04		......		10.04		Not mature
23–3	8	8.67	9.20	......	......	8.67	9.20	
24–1	7	10.82		......		10.82		
24–2	8	9.92		......		9.92		Not mature
24–3	8	6.01	8.92	......	......	6.01	8.92	Not mature
25–1	8	11.26		......		11.26		
25–1	8	11.26		......		11.26		
25–2	8	5.70		......		5.70		
25–3	8	9.33	8.76	......	......	9.33	8.76	

TABLE 68—HANFORD FINE SANDY LOAM, FIRST CROP

MILO B

Planted, June 10, 1916. Harvested, November 20, 1916

Pot	No. plants	Straw		Grain		Total dry matter		Notes
		Weight	Average weight	Weight	Average weight	Weight	Average weight	
14—1	8	10.75		......		10.75		
14–2	8	10.95		......		10.95		
14–3	8	8.84	10.18	......	......	8.84	10.18	
15–1	5	5.25		......		5.25		
15–2	4	4.62		......		4.62		
15–3	2	3.92	4.60	......	......	3.92	4.60	
16–1	7	7.36		......	·	7.36		
16–2	2	2.18		......		2.18		
16–3	4	2.74	4.09	......	......	2.74	4.09	
19–1	3	3.73		......		3.73		
19–2	8	4.79		......		4.79		
19–3	8	9.60	6.04	......	......	9.60	6.04	
20–1	8	8.14		......		8.14		
20–2	8	3.23		......		3.23		
20–3	8	3.22	4.86	......	......	3.22	4.86	
22–1	6	4.74		......		4.74		
22–2	5	3.01		......		3.01		
22–3	7	3.19	3.64	......	......	3.19	3.64	
23–1	8	5.68		......		5.68		
23–2	5	7.72		......		7.72		
23–3	8	6.93	6.78	......	......	6.93	6.78	
24–1	3	3.16		......		3.16		
24–2	6	5.64 ·		......		5.64		
24–3	6	3.26	4.02	......	......	3.26	4.02	
25–1	4	3.07		......		3.07		
25–2	3	2.34		......		2.34		
25–3	8	4.34	3.25	......	......	4.34	3.25	

TABLE 69—HANFORD FINE SANDY LOAM, FIRST CROP

MILLET

Planted, June 10, 1916. Harvested: Nos. 15–25, September 20, 1916; No. 14, October 6, 1916

Pot	No. plants	Straw		Grain		Total dry matter		Notes
		Weight	Average weight	Weight	Average weight	Weight	Average weight	
14–1	12	3.75		2.90		6.65		
14–2	13	4.23		2.95		7.18		
14–3	14	3.46	3.81	2.01	2.62	5.47	6.43	
15–1	12	3.63		1.02		4.65		
15–2	12	4.63		1.31		5.93		
15–3	12	3.86	4.04	1.12	1.15	4.98	5.19	
16–1	13	1.96		0.74		2.70		
16–2	12	3.10		1.81		4.91		
16–3	12	1.52	2.19	0.73	1.09	2.25	3.29	
19–1	12	1.85		0.73		2.58		Seed immature
19–2	12	1.71		0.76		2.48		Poor. Lack of
19–3	12	2.00	1.85	0.69	0.73	2.69	2.58	drainage?
20–1	12	6.54		2.78		9.32		Possible error in
20–2	12	1.70		1.01		2.71		grain weight.
20–3	12	6.57	6.55	2.21	2.50	8.78	9.05	Original shows 6 grams
22–1	12	2.04		0.65		2.69		
22–2	12	2.32		0.68		3.00		
22–3	12	4.44	2.93	1.90	1.08	6.34	4.01	
23–1	12	6.12		1.21		7.33		
23–2	12	6.13		2.14		8.27		
23–3	12	6.01	6.08	1.97	1.78	7.99	7.86	
24–1	12	4.18		1.50		5.69		
24–2	12	2.80		0.91		3.70		
24–3	11	4.89	3.96	2.08	1.50	6.98	5.46	
25–1	12	2.06		0.77		2.83		
25–2	12	2.01		0.51		2.52		
25–3	12	4.31	2.79	2.15	1.14	6.46	3.94	

TABLE 70—HANFORD FINE SANDY LOAM, FIRST CROP

SOY BEANS

Planted, June 10, 1916.   Harvested, December 11, 1916

Pot	No. plants	Straw		Beans		Total dry matter		Notes
		Weight	Average weight	Weight	Average weight	Weight	Average weight	
14–1	6	16.69		......		16.69		Immature seed
14–2	6	16.28		......		16.28		Immature seed
14–3	6	11.89	14.95	0.44	0.15	12.33	15.10	Immature seed
15–1	6	14.08		0.23		14.31	.	Immature seed
15–2	6	5.17		......		5.17		Immature seed
15–3	6	6.53	8.59	......	0.08	6.53	8.67	Immature seed
16–1	6	12.63		0.32		12.95		Immature seed
16–2	6	14.60		......		14.60		Immature seed
16–3	6	16.60	14.61	......	0.11	16.60	14.72	Immature seed
19–1	6	12.84		......		12.84		Immature seed
19–2	6	11.68		......		11.68		Immature seed
19–3	6	16.03	13.52	......	......	16.03	13.52	Immature seed
20–1	6	8.77		......		8.77		Immature seed
20–2	6	16.33		......		16.33		Immature seed
20–3	6	14.27	13.13	......	......	14.27	13.13	Immature seed
22–1	6	20.28		......		20.28		Immature seed
22–2	6	19.44		......		19.44		Immature seed
22–3	6	15.60	18.44	......	......	15.60	18.44	Immature seed
23–1	6	21.42		......		21.42		No seed
23–2	6	20.75		......		20.75		No seed
23–3	6	20.68	20.95	......	......	20.68	20.95	Immature seed
24–1	6	17.37		......		17.37		Immature seed
24–2	6	21.24		......		21.24		Immature seed
24–3	6	13.70	17.43	......	......	13.70	17.43	Immature seed
25–1	6	5.53		......		5.53		Rained on; excluded from average
25–2	6	17.85		......		17.85		No seed
25–3	6	21.58	19.71	......	......	21.58	19.71	Immature seed

TABLE 71—HANFORD FINE SANDY LOAM, FIRST CROP

COWPEAS A

Planted, June 10, 1916. Harvested, October 21, 1916 ·

Pot	No. plants	Straw		Beans		Total dry matter		Notes
		Weight	Average weight	Weight	Average weight	Weight	Average weight	
14–1	6	2.99		0.93		3.92		
14–2	6	3.52		......		3.52		
14–3	6	4.18	3.56	......	......	4.18	3.87	
15–1	..	......		......		......		
15–2	..	......		......		......		
15–3	..	......		......		......		
16–1	1	2.98		......		2.98		Immature seed
16–2	3	3.05		1.50		4.58		
16–3	4	2.60	2.88	2.16	1.22	4.76	4.10	
19–1	6	1.49		0.27		1.77		
19–2	6	1.54		0.28		1.82		
19–3	2	1.10	1.38	0.47	0.34	1.57	1.72	
20–1	6	2.86		0.32		3.18		
20–2	6	2.08		0.58		2.66		
20–3	6	2.99	2.64	0.33	0.41	3.32	3.05	
22–1	5	1.80		0.23		2.02		
22–2	..	......		......		......		
22–3	2	1.96	1.88	0.39	0.31	2.35	2.19	
23–1	..	.....		......		......		
23–2	1	1.80		0.76		2.57		
23–3	..	......	1.80	......	0.76	......	2.57	
24–1	2	1.06		0.25		1.30		
24–2	1	1.80		1.29		3.09		
24–3	2	1.75	1.54	0.45	0.66	2.20	2.20	
25–1	3	2.74		2.03		4.78		
25–2	1	1.88		2.28		4.17		
25–3	2	2.12	2.25	1.24	1.85	3.36	4.10	

TABLE 72—HANFORD FINE SANDY LOAM, FIRST CROP

COWPEAS B

Planted, June 10, 1916. Harvested, November 21, 1916

Pot	No. plants	Straw		Beans		Total dry matter		Notes
		Weight	Average weight	Weight	Average weight	Weight	Average weight	
14–1	6	3.94		......		3.94		
14–2	6	5.93		......		5.92		
14–3	6	3.32	4.39	......	......	3.32	4.39	
15–1	6	7.24		......		7.24		
15–2	6	5.34		......		5.34		
15–3	6	4.61	5.74	......	......	4.61	5.74	
16–1	6	5.90		......		5.90		
16–2	6	5.82		......		5.82		
16–3	6	3.65	5.12	......	......	3.65	5.12	
19–1	6	3.34		......		3.34		
19–2	6	3.38		......		3.38		
19–3	6	3.87	3.53	......	......	3.87	3.53	1 died early
20–1	6	3.09		......		3.09		
20–2	6	3.15		.. ...		3.15		1 died early
20–3	6	2.80	3.01	......	......	2.80	3.01	
22–1	6	3.12		......		3.12		
22–2	6	3.61		......		3.61		
22–3	6	4.92	3.88	......	......	4.92	3.88	
23–1	6	4.59		......		4.59		
23–2	6	6.04		......		6.04		
23–3	6	4.08	4.90	......	......	4.08	4.90	
24–1	6	3.81		.. ...		3.81		
24–2	5	4.28		.. .		4.28		
24–3	6	6.42	4.84	. ...	......	6.42	4.84	
25–1	5	4.17		......		4.17		
25–2	6	3.93		... ..		3.93		1 died early
25–3	6	4.86	4.32	......	......	4.86	4.32	

Hanford fine sandy loam. Second crop.—Barley (twice), oats, wheat, bur clover (*Medicago* sp.), and *Melilotus indica* were the indicator crops used when the Hanford soils were planted the second time. In all cases a sufficient quantity of seed was used to insure the growth of more plants than would be raised to maturity. Later the plants in each pot were thinned to six in number, good specimens and well

spaced. The final number of plants varied, but was almost always six. An attempt was made to reduce at least partially the shading and exposure effects. The pots were periodically changed from position to position on the bench.

The total dry weights produced on the several soils are interesting (tables 73–78, and fig. 33). The grains gave more uniform results in this crop than in the first. Soils nos. 14 and 23 show the best crops, and they are the ones that have the highest amounts of total nitrogen. The legumes selected must have been particularly well adapted to the growing conditions and the soils, because the growth was enormous. In the amount of dry matter produced the parallelism between the two legumes from soil to soil is close. It is noteworthy that soil no. 14,
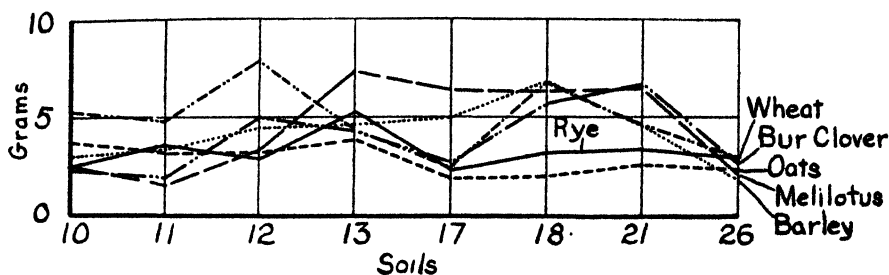

Fig. 32

Fig. 32. Graph showing the total dry matter produced by barley, wheat, oats, rye, bur clover, and *Melilotus indica* on the eight samples of San Joaquin sandy loam. First and only crop.

which showed the highest total nitrogen and produced the most dry matter from the grains, gave the poorest crop of legumes. The notes taken during the growing period show that the relative appearances quite early and throughout the period of growth are usually a good index to the relative amounts of dry matter produced. This is so, even though the photographs of the mature plants do not show differences nearly as great in magnitude as do the dry weights.

This type does not show any marked tendency for the several soils to approach a more uniform crop producing capacity through being kept under the same conditions. In fact, the second crop shows greater variations than the first. And this type does not show that these nine soils, mapped under a single type name, are closely similar to one another in crop producing power.

TABLE 73—HANFORD FINE SANDY LOAM, SECOND CROP

WHEAT (following millet)

Planted, October 30, 1916. Harvested, June 21, 1917

Pot	No. plants	Straw		Grain		Total dry matter		Notes
		Weight	Average weight	Weight	Average weight	Weight	Average weight	
14–1	6	10.75		3.55		14.30		
14–2	5	5.20		2.10		7.30		
14–3	6	14.85	10.26	6.45	4.03	21.30	14.30	
15–1	6	3.55		1.30		4.65		
15–2	6	4.85		1.50		6.35		
15–3	6	2.80	3.66	1.10	1.30	3.90	4.96	
16–1	6	3.20		0.95		4.15		
16–2	6	8.20		3.70		11.90		Rained on, excluded from average
16–3	6	2.80	3.00	0.70	0.82	3.50	3.82	
19–1	6	2.80		0.75		3.55		
19–2	6	2.80		0.65		3.45		
19–3	6	2.20	2.60	0.60	0.66	2.80	3.26	
20–1	6	5.45		2.80		8.25		
20–2	6	4.05		1.55		5.60		
20–3	6	21.35	4.75	12.90	2.17	34.25	6.90	Rained on, excluded from average
22–1	6	4.15		0.90		5.05		
22–2	6	3.95		0.40		4.35		
22–3	6	4.45	4.18	0.90	0.73	5.35	4.92	
23–1	6	4.90		1.60		6.50		
23–2	6	4.75		1.60		6.35		
23–3	6	3.75	4.46	1.10	1.43	4.85	5.90	
24–1	6	18.60		8.30		26.90		Rained on, excluded from average
24–2	6	3.20		0.90		4.10		Rained on, excluded from average
24–3	6	23.75	3.20	5.40	0.90	29.15	4.10	Rained on, excluded from average
25–1	6	15.75		9.05		24.80		
25–2	6	2.50		0.35		2.85		
25–3	6	2.25	2.37	0.80	0.57	3.05	2.95	

TABLE 74—HANFORD FINE SANDY LOAM, SECOND CROP

OATS (following milo A)

Planted, November 22, 1916. Harvested, June 18, 1917

Pot	No. plants	Straw		Grain		Total dry matter		Notes
		Weight	Average weight	Weight	Average weight	Weight	Average weight	
14–1	6	3.80		2.90		6.70		
14–2	6	3.40		1.85		5.25		
14–3	6	3.20	3.47	2.40	2.38	5.65	5.86	
15–1	6	2.45		1.35		3.80		
15–2	6	1.75		1.25		3.00		
15–3	6	2.00	2.06	1.50	1.36	3.50	3.43	
16–1	6	11.15		8.40		19.55		Rained on, excluded from average
16–2	6	2.15		2.30		4.45		Pot saturated with soluble salts, excluded from average
16–3	6	1.15	2.15	0.70	2.30	1.85	4.45	
19–1	6	1.75		1.25		3.00		
19–2	6	4.55		2.95		7.50		
19–3	6	1.35	2.55	0.95	1.72	2.30	4.27	
20–1	6	10.45		6.30		16.75		Rained on, excluded from average
20–2	6	1.55		1.05		2.60		
20–3	6	1.65	1.60	1.00	1.02	2.65	2.62	
22–1	6	1.65		1.10		2.75		
22–2	6	2.10		1.15		3.25		
22–3	6	2.50	2.08	1.50	1.25	4.00	3.33	
23–1	6	2.70		1.55		4.25		
23–2	6	1.90		1.60		3.50		
23–3	6	3.20	2.60	2.00	1.71	5.20	4.32	
24–1	6	4.80		3.10		7.90		
24–2	6	16.75		9.80		26.55		Rained on, excluded from average
24–3	6	3.35	4.07	2.35	2.73	5.70	6.80	
25–1	6	1.95		1.30		3.25		
25–3	6	2.25	2.00	1.40	1.30	3.65	3.30	
25–2	6	1.80		1.20		3.00		

TABLE 75—HANFORD FINE SANDY LOAM, SECOND CROP

BARLEY A (following cowpeas A)

Planted, October 30, 1916.   Harvested, May 20, 1917

Pot	No. plants	Straw		Grain		Total dry matter		Notes
		Weight	Average weight	Weight	Average weight	Weight	Average weight	
14–1	6	4.75		4.30		9.05		
14–2	6	9.22		9.00		18.22		
14–3	6	11.97	8.65	10.85	8.05	22.82	16.69	
15–1	6	15.47		15.30		30.77		Rained on, excluded from average
15–2	6	3.78		3.29		7.07		
15–3	6	5.00	4.39	4.12	3.70	9.12	8.09	
16–1	6	7.28		6.42		13.70		
16–2	6	2.55		2.55		5.10		
16–3	6	2.20	4.01	1.71	3.56	3.91	7.57	
19–1	6	2.82		1.80		4.62		
19–2	6	2.39		1.91		4.30		
19–3	6	2.89	2.70	2.25	1.98	5.14	4.68	
20–1	6	3.57		2.90		6.47		
20–2	6	3.32		2.80		6.12		
20–3	6	19.35	3.44	7.45	2.85	26.70	6.29	Rained on, excluded from average
22–1	6	2.73		2.07		4.80		
22–2	6	5.89		3.53		9.42		
22–3	6	3.69	4.10	2.73	2.78	6.42	6.88	
23–1	6	5.29		3.35		8.64		
23–2	6	6.19		4.23		10.42		
23–3	6	7.98	6.24	4.20	3.93	12.18	10.41	
24–1	6	3.07		2.54		5.61		
24–2	6	21.85		9.75		31.60		
24–3	6	4.73	3.90	3.57	3.05	8.30	6.95	
	6	2.47		1.75		4.22		Rained on, excluded from average
25–2	6	Lost		......		......		Pot broken, excluded from average
25–3	6	3.01	2.74	2.18	1.96	5.19	4.70	

TABLE 76—HANFORD FINE SANDY LOAM, SECOND CROP

BARLEY B (following soy beans)

Planted, January 31, 1917. Harvested, June 21, 1917

Pot	No. plants	Straw		Grain		Total dry matter		Notes
		Weight	Average weight	Weight	Average weight	Weight	Average weight	
14–1	6	9.55		6.80		16.35		
14–2	6	6.05		5.40		11.45		
14–3	6	3.80	6.47	2.10	4.76	5.90	11.23	
15–1	6	3.50		2.80		6.30		
15–2	6	3.20		1.70		4.90		
15–3	6	4.05	3.58	2.60	2.36	6.65	5.95	
16–1	6	3.10		1.45		4.55		
16–2	6	9.20		8.20		17.40		Rained on, excluded from average
16–3	6	7.35	3.10	4.50	1.45	11.85	4.55	Rained on, excluded from average
19–1	6	3.05		0.80		3.85		
19–2	6	2.65		2.20		4.85		
19–3	6	2.15	2.62	1.85	1.61	4.00	4.23	
20–1	6	3.35		2.60		5.95		
20–2	6	4.20		3.20		7.40		
20–3	6	2.55	3.36	2.15	2.65	4.70	6.02	
22–1	6	2.05		1.75		3.80		
22–2	6	2.90		2.35		5.25		
22–3	6	3.15	2.70	2.25	2.12	5.40	4.82	
23–1	6	3.10		2.05		5.15		
23–2	6	3.10		2.95		6.05		
23–3	6	3.40	3.20	2.75	2.58	6.15	5.78	
24–1	6	3.10		1.45		3.70		
24–2	6	10.10		5.80		15.90		Rained on, excluded from average
24–3	6	3.05	2.65	2.35	1.90	5.40	4.55	
25–1	6	3.35		2.90		6.25		
25–2	6	3.10		1.85		4.95		
25–3	6	4.70	3.72	4.60	3.12	9.30	6.83	

TABLE 77—HANFORD FINE SANDY LOAM, SECOND CROP

Melilotus indica (following cowpeas B)

Planted, November 22, 1916. Harvested, June 21, 1917

Pot	No. plants	Straw		Unhulled seed		Total dry matter		Notes
		Weight	Average weight	Weight	Average weight	Weight	Average weight	
14–1	6	17.00		15.80		32.80		
14–3	6	13.25		16.45		29.70		
14–3	6	4.40	15.12	3.10	16.12	7.50	31.25	Excluded from average
15–1	6	35.00		34.75		69.75		
15–2	6	24.85		27.28		52.05		
15–3	6	28.95	29.60	32.70	31.58	61.65	61.15	
16–1	5	23.50		24.90		48.40		
16–2	6	30.80		25.50		56.30		
16–3	6	23.65	25.98	25.70	25.37	49.35	51.35	
19–1	6	20.50		18.35		38.85		
19–2	6	26.90		23.20		50.10		
19–3	6	26.20	24.53	27.40	22.98	53.60	47.52	
20–1	6	20.55		17.80		38.35		
20–2	6	20.75		21.20		41.95		
20–3	6	28.85	23.38	26.05	21.68	54.90	45.07	
22–1	6	28.00		28.10		56.10		
22–2	6	32.30		34.20		66.50		
22–3	6	28.25	29.52	31.85	31.38	60.10	60.90	
23–1	6	38.05		34.25		72.30		
23–2	6	34.40		36.55		70.95		
23–3	6	32.25	34.90	32.35	34.38	64.60	69.28	
24–1	6	37.35		31.40		68.75		
24–2	6	25.90		28.10		54.00		
24–3	6	29.05	30.77	30.15	29.88	59.20	60.65	
25–1	6	25.35		30.45		55.80		
25–2	6	33.90		35.90		69.80		
25–3	6	32.10	30.45	36.65	34.33	68.75	64.78	

TABLE 78—HANFORD FINE SANDY LOAM, SECOND CROP
BUR CLOVER (following milo B)

Planted, November 22, 1916. Harvested, June 25, 1917

Pot	No plants	Straw		Burs		Total dry matter		Notes
		Weight	Average weight	Weight	Average weight	Weight	Average weight	
14–1	7	6.70		17.55		24.25		
14–2	6	7.00		16.85		23.85		
14–3	6	6.10	6.60	14.50	16.30	20.60	22.90	
15–1	6	13.30		29.10		42.40		
15–2	6	14.45		33.10		47.55		
15–3	6	17.10	14.95	26.65	29.62	43.75	44.56	
16–1	6	8.85		15.40		24.25		
16–2	6	12.25		29.60		41.85		
16–3	6	10.05	10.38	21.90	22.30	31.95	32.68	
19–1	6	9.90		19.90		29.80		
19–2	6	7.70		17.80		25.50		
19–3	6	8.20	8.60	22.40	20.03	30.60	28.63	
20–1	6	7.90		22.50		30.40		
20–2	6	9.75		23.30		33.05		
20–3	6	8.70	8.78	20.50	22.10	29.20	30.88	
22–1	6	15.90		38.00		53.90		
22–2	6	13.20		23.40		36.60		
22–3	6	14.50	14.53	31.30	30.90	45.80	45.43	
23–1	6	14.45		37.40		51.85		
23–2	6	13.55		27.30		40.85		
23–3	6	12.05	13.35	28.00	30.90	40.05	44.25	
24–1	6	10.60		24.30		34.90		
24–2	6	12.10		34.10		46.20		
24–3	6	10.25	10.98	24.00	27.46	34.25	38.45	
25–1	6	17.90		40.00		57.90		
25–2	6	14.60		30.80		45.40		
25–3	6	13.35	15.28	26.40	32.40	39.75	47.68	

San Joaquin sandy loam.—The samples of this type were the last to be weighed into pots and planted, because of the lack of available greenhouse space; therefore the time allowed for the growing of but one crop, instead of two, on each pot of soil. The crops used were wheat, barley, rye, oats, bur clover (*Medicago* sp.), and *Melilotus indica*. As was done for the other types, an excess of seed was planted. When the plants were well established, thinning reduced the number to six plants per pot.

Since the specific gravity of this soil was high, because of the large amount of quartz and the small amount of organic matter in its composition, six kilos of soil, instead of five, were weighed out into each pot. The samples of this type have the very annoying peculiarities of becoming very mushy if an excess of water be added, and of setting

with a very hard surface on drying. This makes the soils hard to handle in greenhouse pot culture work.

The variation in crop growth from soil to soil, as shown by the total dry matter produced (tables 79–84 and fig. 32), is rather marked. That the several samples do not show equal crop producing powers is very evident, though with regard to the several indicator crops the soils would frequently not maintain the same order. Soil no. 26 gave the poorest yields with all six crops. Except for wheat, the soils nos. 10, 11, and 12 gave low yields with both the grains and the legumes. It is interesting to note that wheat gave relatively high yields with a number of the soils, and wheat has probably been raised on these soils more than any other one crop. This series shows that, as far as the samples represent the type and the crops used represent crops as a whole, the soils mapped under a given type name are not closely similar in crop producing power under greenhouse conditions.

TABLE 79—SAN JOAQUIN SANDY LOAM

RYE

Planted, November 22, 1916. Harvested, June 21, 1917

Pot	No plants	Straw Weight	Straw Average weight	Grain Weight	Grain Average weight	Total dry matter Weight	Total dry matter Average weight	Notes
10–1	6	1.70		0.30		2.00		
10–2	6	2.30		0.35		2.65		
10–3	6	2.05	2.02	0.65	0.43	2.70	2.45	
11–1	6	3.15		0.70		3.85		
11–2	6	2.25		0.70		2.95		
11–3	4	3.20	2.87	0.70	0.70	3.90	3.57	
12–1	6	1.65		0.45		2.10		
12–2	6	2.45		0.85		3.30		
12–3	6	2.40	2.17	0.65	0.65	3.05	2.82	
13–1	6	4.20		1.25		5 45		
13–2	6	4 30		0.80		5.10		
13–3	6	3.75	4.08	1.60	1.22	5.35	5.30	
17–1	6	7.55		1.60		9.15		Rained on
17–2	6	1.95		0.55		2.50		
17–3	6	1.80	1.87	0.45	0.50	2.25	2.37	
18–1	6	2.35		0.85		3.20		
18–2	6	0.90		0.30		1.20		
18–3	6	3.70	2.32	1.20	0.78	4.90	3.10	
21–1	6	2.20		0.80		3.00		
21–2	6	2.70		0.95		3.65		
21–3	6	6.55	2.45	2.35	0.87	8.90	3.33	Rained on
26–1	6	1.50		0.60		2.10		
26–2	6	2.55		0.75		3.30		
26–3	6	2.50	2.18	0.70	0.68	3.20	2.87	
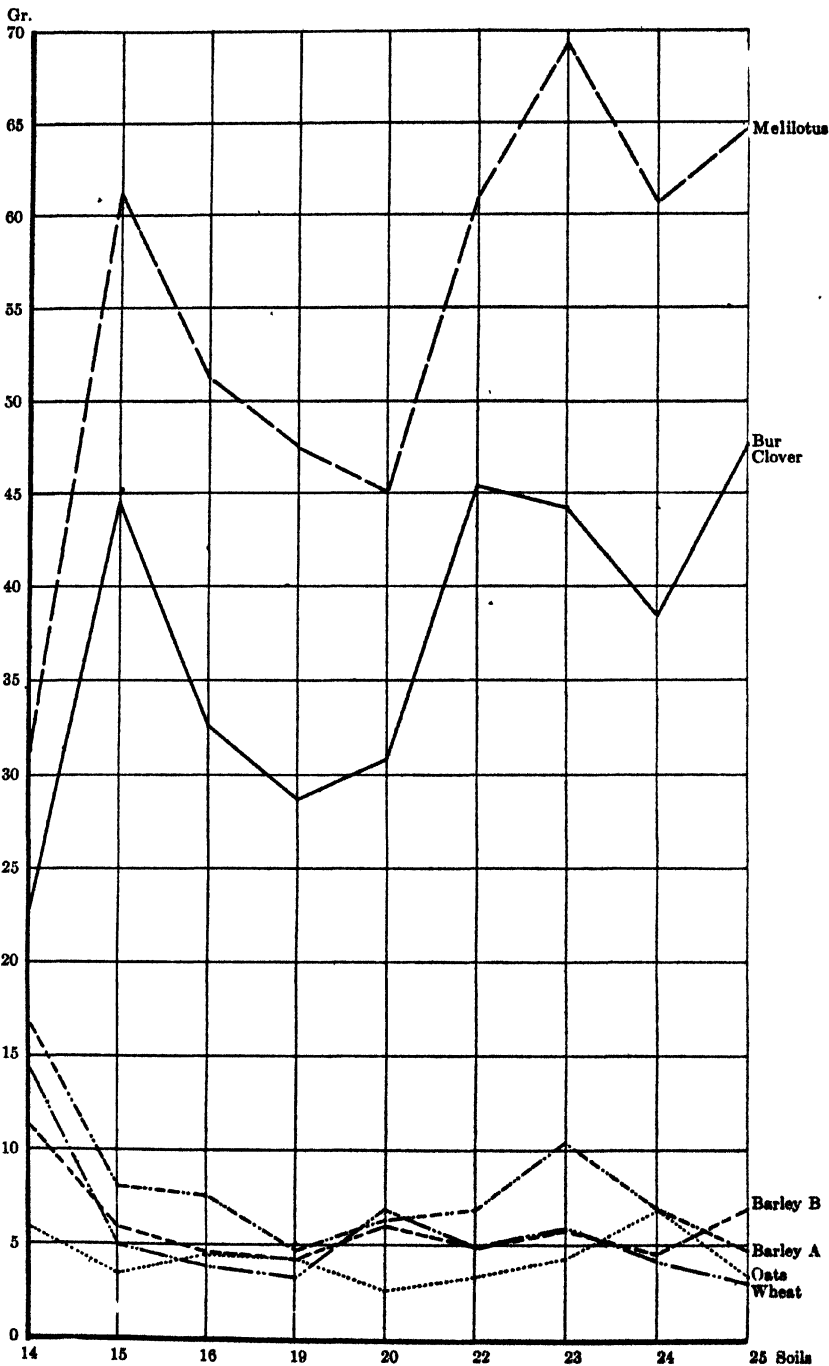
Fig. 33. Graph showing the total dry matter produced by wheat, oats, barley (two series), bur clover, and *Melilotus indica* on the nine samples of Hanford fine sandy loam. Second crop.

TABLE 80—SAN JOAQUIN SANDY LOAM

BARLEY

Planted, October 30, 1916.   Harvested, June 17, 1917

Pot	No. plants	Straw Weight	Straw Average weight	Grain Weight	Grain Average weight	Total dry matter Weight	Total dry matter Average weight	Notes
10–1	6	2.93		0.92		3.85		
10–2	6	1.87		0.81		2.68		
10–3	6	1.47	2.09	0.85	0.86	2.32	2.95	
11–1	6	1.91		0.66		2.57		
11–2	6	2.02		1.28		3.30		
11–3	6	2.97	2.30	0.90	0.95	3.87	3.25	
12–1	6	10.27		4.95		15.22		Rained on; exclud-ed from average
12–2	6	3.60		1.32		4.92		
12–3	6	3.49	3.54	0.43	0.87	3.92	4.42	
13–1	6	2.14		1.46		3.60		
13–2	6	3.19		1.78		4.97		
13–3	6	3.28	2.87	1.77	1.67	5.05	4.53	
17–1	6	3.89		2.17		6.06		
17–2	6	3.74		1.80		5.54		
17–3	6	2.44	3.35	0.80	1.59	3.24	4.95	
18–1	6	4.65		1.93		6.58		
18–2	6	3.74		1.94		5.68		
18–3	6	5.61	4.66	2.34	2.07	7.95	6.74	
21–1	6	2.05		1.53		3.58		
21–2	6	2.10		1.80		3.90		
21–3	6	3.81	2.65	2.33	1.88	6.14	4.54	
26–1	6	1.12		0.63		1.75		
26–2	6	1.08		0.41		1.49		
26–3	6	1.20	1.13	0.70	0.58	1.90	1.71	

TABLE 81—SAN JOAQUIN SANDY LOAM

WHEAT

Planted, October 30, 1916.   Harvested, June 21, 1917

Pot	No. plants	Straw		Grain		Total dry matter		Notes
		Weight	Average weight	Weight	Average weight	Weight	Average weight	
10–1	6	3.59		0.85		4.80		
10–2	6	3.45		0.45		3.90		
10–3	6	6.35	4.58	0.75	0.68	7.10	5.26	
11–1	6	5.60		1.15		6.75		
11–2	6	2.75		0.60		3.35		
11–3	6	3.45	3.93	0.70	0.81	4.15	4.75	
12–1	6	6.85		2.00		8.85		
12–2	6	7.50		1.35		8.85 ·		
12–3	6	4.45	6.27	1.35	1.56	5.80	7.83	
13–1	6	3.90		0.85		4.75		
13–2	6	3.25		0.45		3.70		
˙13–2	6	3.95	3.70	0.75	0.68	4.70	4.38	
17–1	6	2.70		0.25		2.95		
17–2	6	1.20		0.45		1.65		
17–3	6	2.75	2.21	none	0.23	2.75	2.45	
18–1	6	5.90		1.50		7.40		
18–2	6	7.90		2.40		10.30		Rained on
18–3	6	5.00	5.45	1.00	1.25	6.00	6.70	
21–1	6	3.10		1.05		4.15		
21–2	5	4.30		0.75		5.05		
21–3	6	8.40	3.70	2.45	0.90	10.85	4.60	Rained on
26–1	6	2.35		0.55		2.90		
26–2	6	0.40		none		0.40		Rained on
26–3	6	2.60	2.47	0.35	0.45	2.95	2.92	

TABLE 82—SAN JOAQUIN SANDY LOAM

OATS

Planted, November 22, 1916.   Harvested, June 17, 1917

| Pot | No. plants | Straw | | Grain | | Total dry matter | | Notes |
		Weight	Average weight	Weight	Average weight	Weight	Average weight	
10–1	6	2.25		0.90		3.15		
10–2	6	3.65		1.90		5.55		
10–3	6	1.70	2.53	0.50	1.10	2.20	3.63	
11–1	6	2.25		1.25		3.50		
11–2	6	1.75		0.95		2.70		
11–3	6	2.10	2.03	1.00	1.07	3.10	3.10	
12–1	6	1.70		0.90		2.60		
12–2	6	2.40		1.00		3.40		
12–3	6	2.35	2.15	1.05	0.98	3.40	3.13	
13–1	6	2.25		1.20		3.45		
13–2	6	2.40		1.10		3.50		
13–3	6	2.70	2.45	1.70	1.33	4.40	3.78	
17–1	6	0.80		0.55		1.35		
17–2	6	1.50		0.90		2.40		
17–3	6	1.25	1.90	0.70	0.72	1.95	1.90	
18–1	6	1.70		1.00		2.70		
18–2	6	1.15		0.60		1.75		
18–3	6	1.10	1.32	0.50	0.70	1.60	2.02	
21–1	6	1.85		0.95		2.80		
21–2	6	2.35		1.05		3.40		
21–3	6	1.00	1.73	0.55	0.85	1.55	2.58	
26–1	6	1.55		0.60		2.15		
26–2	6	1.35		0.80		2.15		
26–3	6	1.65	1.52	0.70	0.70	2.35	2.22	

TABLE 83—SAN JOAQUIN SANDY LOAM
BUR CLOVER

Planted, November 22, 1916.   Harvested, June 17, 1917

Pot	No plants	Straw		Seed in burs		Total dry matter		Notes
		Weight	Average weight	Weight	Average weight	Weight	Average weight	
10–1	6	0.50		0.95		1.45		
10–2	6	1.50		1.65		3.15		
10–3	6	0.50	0.83	1.75	1.45	2.25	2.28	
11–1	6	0.90		2.00		2.90		
11–2	6	0.25		1.00		1.25		
11–3	6	0.30	0.48	1.10	1.37	1.40	1.85	
12–1	6	0.90		3.00		3.90		
12–2	6	2.15		5.30		7.45		
12–3	6	1.50	1.52	1.90	3.40	3.40	4.92	
13–1	6	1.55		3.45		5.00		
13–2	6	0.75		2.80		3.55		
13–3	6	4.35	1.15	5.70	3.12	9.05	4.27	Excluded from average
17–1	6	0.70		2.05		2.75		
17–2	6	2.35		3.85		6.20		Excluded from average
17–3	6	0.90	0.80	1.70	1.87	2.60	2.67	
18–1	6	1.20		3.40		4.60		
18–2	6	3.25		6.65		9.90		Excluded from average
18–3	6	1.80	1.50	4.85	4.12	6.65	5.62	
21–1	6	3.35		3.70		7.05		
21–2	6	2.00		3.90		5.90		
21–3	6	1.75	2.37	5.15	4.25	6.90	6.62	
26–1	6	0.60		1.45		2.05		
26–2	6	1.20		2.75		3.95		
26–3	6	0.40	0.73	1.30	1.83	1.70	2.56	

TABLE 84—SAN JOAQUIN SANDY LOAM

Melilotus indica

Planted, November 22, 1916.   Harvested, June 21, 1917.

| Pot | No. plants | Straw | | Unhulled seed | | Total dry matter | | Notes |
		Weight	Average weight	Weight	Average weight	Weight	Average weight	
10–1	6	1.20		1.20		2.40		
10–2	6	1.03		0.92		1.95		
10–3	6	1.30	1.18	1.65	1.26	2.95	2.44	
11–1	6	1.05		0.85		1.90		
11–2	6	0.50		0.35		0.85		
11–3	6	1.00	0.85	0.80	0.67	1.80	1.52	
12–1	6	1.07		2.05		3.12		
12–2	6	1.70		2.45		4.15		
12–3	6	1.20	1.33	1.40	1.96	2.60	3.29	
13–1	6	3.05		3.70		6.75		
13–2	6	3.10		3.95		7.05		
13–3	6	3.50	3.22	4.45	4.03	7.95	7.25	
17–1	6	3.05		4.05		7.10		
17–2	6	2.25		3.55		5.80		
17–3	6	2.85	2.72	3.20	3.60	6.05	6.32	
18–1	6	3.25		3.90		7.15		
18–2	6	2.05		2.65		4.70		
18–3	6	2.85	2.42	3.95	3.50	6.80	6.22	
21–1	6	2.50		3.40		5.90		
21–2	6	2.65		3.95		6.60		
21 3	6	3.45	2.87	3.30	3.55	6.75	6.42	
26–1	6	1.10		0.85		1.95		
26–2	6	0.95		0.85		1.80		
26–3	6	1.30	1.12	1.05	0.92	2.35	2.04	

GENERAL DISCUSSION

The limited time available for this study made it impossible to make all the determinations upon each of the several horizons of all the soils collected for this study.

It was believed, however, that the additional data were not required, since that already at hand seemed to give ample evidence upon which to base conclusions. Therefore, in many cases determinations were run on the surface horizon only. This makes some of the tables appear incomplete.

On the basis of the preceding results and discussions some general treatment is possible, as well as a more or less critical discussion of the methods of soil surveying pursued by the Bureau of Soils.

The types and the localities of collection of the soils studied were as follows:

Diablo clay adobe:	Thalheim (17)
San Juan Capistrano (1)	Madera (18)
Los Angeles (2)	Merced (21)
Calabasas (5)	Del Mar (26)
Danville (6)	*Hanford fine sandy loam:*
Altamont clay loam	Elk Grove (14)
Walnut (3)	Acampo (15)
San Fernando Valley (4)	Woodbridge (16)
Mission San José (7)	Waterford (19)
San Joaquin sandy loam:	Snelling (20)
North Sacramento (10)	Basset (22)
Lincoln (11)	Anaheim (23)
Wheatland (12)	Los. Angeles (24)
Elk Grove (13)	Van Nuys (25)

NOTE —Figures following localities designate sample numbers

COMPARISONS OF PHYSICAL DATA

The mechanical analyses of the soils were carried out with both the Hilgard elutriator and the Bureau of Soils centrifuge methods. The tedious nature of the elutriator method has been emphasized elsewhere. The results by this method show that the soils of each type as a whole are somewhat similar, though no two are identical and some samples of a type are widely divergent from the rest. The Bureau of Soils method appears to give a sharper and more satisfactory separation into classes than does the elutriator method. This is to be expected since the separates represent greater ranges of particle sizes. As a check on the texture of the samples collected. it shows that some of the soils are not true to name, therefore that all soils mapped under a given type name are not closely similar to one another. Of course, this is the belief of many soil surveyors, but it seems strange that in the present work, where there was the attempt to select soils representative of the class and type chosen for study, that such divergences developed. It is an interesting commentary on the personal equation of the field worker, in this case of the writer, who collected the samples.

With regard to the methods of mechanical analysis, one should not overlook Mohr's work on The Mechanical Analysis of Soils of Java,[30] which gives an excellent discussion of the relative merits of the better known systems of mechanical analysis. He describes a modified centrifuge method preferred by him.

Under a discussion of the physical constants of soils, Free[31] discusses the value of mechanical analysis as a soil constant, and shows that there are three serious errors in the determination, all of which impress themselves upon one making and using such analyses. They are: "(1) disunity of expression; (2) failure to express conditions within the limits of individual groups; and (3) failure to take account of variations in the shapes of the particles." Yet he emphasizes, and rightly so, "that mechanical analysis is by no means useless nor to be belittled as a means of soil investigation."[32]

Moisture equivalents.—This determination showed quite distinct averages for the types, though there was considerable variation within each of the types. Eliminating those samples shown to be non-typical according to the mechanical analysis, the variation within the type is reduced considerably. Yet it cannot be said that as regards this constant that all soils mapped under a given type name, or even those soils under a given type name which the mechanical analysis has shown to be true to name, have closely similar moisture equivalents. Briggs and McLane[33] express the belief that ultimately moisture equivalent determinations will replace mechanical analysis in the classification of soils, because the determination is simple and the result can be expressed as a single constant.

Hygroscopic coefficient.—The two heavy types show averages distinct from those of the two light types, but the wide and erratic variation within the type, together with the nearly universal failure of Briggs and Shantz's formula[34] to convert these values into values even approximating those of the moisture equivalent, leads one to doubt the accuracy of these figures of the hygroscopic coefficient. It is because of the ease of determining the moisture equivalent, and because of the difficulties involved in correctly carrying out the hygroscopic coefficient, that the doubt is cast upon the latter determination.

[30] Bull. Dept. of Agr., Indes Neerland, 1910, no. 41, pp. 33.

[31] Free, E. E., Studies in Soil Physics, Plant World, vol. 14 (1912), nos. 2, 3, 5, 7, 8.

[32] *Ibid.*, p. 29.

[33] Proc. Amer. Soc. Agron., vol. 2 (1910), pp. 138–47.

[34] U. S. Bur. Pl. Ind., Bull. 230 (1912), p. 72.

COMPARISON OF CHEMICAL DATA

The total nitrogen content of the samples of each type varies within somewhat wide limits. The average amounts for the several types are distinct, though the variations are such that some of the quantities of one type overlap those of another type. It is believed that for the types selected the field differentiations do indicate differences.

Regarding the humus content of the four types under consideration, the results are somewhat different. The average amounts of humus are almost alike in three of the four types, while the nitrogen-poor San Joaquin soil has an average of about half that of the others. Within the type the soils may be very nearly alike in the humus content, as is the case in two of the types, or may be widely variable, as in the Hanford fine sandy loam. It should be noted that the amount of humus as shown by the method used, is not indicated by the intensity of the color either of the soil or of the resulting extract. This confirms the findings of Gortner, which are cited elsewhere.

There was quite a wide range shown in the results of the determination of the loss on ignition. The Diablo and Altamont soils, because of the heavier textures and the relatively large amounts of combined water, and of considerable amounts of $CaCO_3$ in at least one case, gave high losses on ignition. The averages were close, 6.8% for the Diablo, and 6.7% for the Altamont. The Hanford soils were lower, though with a wider range. Soil no. 14, with 6.9% loss on ignition, shows almost double that of any other soil in the type. The San Joaquin soils, with an average of 2.6%, show the lowest average loss on ignition. The smaller amounts of organic matter in these soils is one reason for the smaller loss. The two heavier types have averages close together, and the lighter types have averages not far apart, but because of the wide variations within each type, the results of the determination of the loss on ignition certainly do not show that all soils classified in one type are closely similar.

Hall and Russell, in their discussion of the soils of southeastern England,[35] consider of value the ratio of $\frac{\% \text{ total nitrogen}}{\% \text{ loss on ignition}}$, but applying this ratio to the California soils under consideration does not seem to give any relations of value. The Diablo ratio varies from 0.0136 to 0.0158, the Altamont from 0.0141 to 0.0204, the San Joaquin from 0.0144 to 0.0232, and the Hanford from 0.011 to 0.0172.

[35] Jour. Agr. Sci., vol. 4 (1911), pp. 182–223.

The calcium (as CaO) content of the soils is interesting especially because of the variability. The Altamont samples show the greatest variation, for the largest quantity of CaO is about seven times the smallest. The San Joaquin samples are second, with the largest over six times the smallest. The Diablo samples are third, with the largest over five times the smallest, while the Hanford soils show the least variation, the largest being less than twice the smallest. There are quite marked differences between the averages of the Diablo, Altamont, and Hanford soils (the San Joaquin samples are intermediate), but the wide variations within the types greatly minimize any significance the averages might have. Hence it is not possible to state that one or another type, as represented by these samples, is characterized by high, low, or moderate amounts of calcium.

As the analyses of the samples for calcium failed to point out any striking characteristics, unless it be that of variability, so it is with magnesium. Magnesium (as MgO) is variable within each of the four types. The largest quantity is about three times the smallest in the Diablo, San Joaquin, and Hanford types, while in the Altamont the largest is twenty-seven times the smallest. Considering the Hanford and San Joaquin, or the Diablo and San Joaquin, it is seen that the curves do not overlap, while the Diablo and Altamont, or the Diablo and Hanford curves do. The averages of the four types are distinct, except between the Hanford and Diablo, which are quite close. But, here again, because of the more or less wide range of values within each of the types, the averages are of little significance. The lime-magnesia ratio is very variable in these soils. Comparing the calcium and magnesium curves for the several soils gives a good idea of the relations. The Diablo curves are quite similar except for soil no. 6, which shows 3% MgO and 0.5% CaO. In the Altamont soils the curves are somewhat similar in direction, though the ratios differ widely. In the Hanford and San Joaquin types the ratios of CaO and MgO are also far from constant, yet it is readily seen from the graphs that the amount of magnesium varies more or less directly with the amount of calcium.

Respecting the total phosphorus (as P_2O_5), if the San Joaquin and Hanford samples alone be considered, there would be no doubt as to the significance of the field separation, the variations within the type notwithstanding. But when the other two types are considered, the case is not so good in favor of the field classification. The Diablo soils show considerable variation in the amount of P_2O_2, while the three

Altamont samples show much variation. Therefore with reference to the amount of phosphorus, and the types studied, the separation into types may or may not be of significance.

If the results of the potassium (K_2O) determinations are compared, it is very evident that but one conclusion can be drawn, and that is that the variations in the amount of potassium within each type are great enough so that any differences between the averages of the several types have no significance whatsoever. Therefore, with regard to total potassium the field separation of soils as represented by these twenty-four samples of four types means nothing.

Comparison of Bacteriological Data

The wealth of the data obtained from over nine hundred bacteriological tumbler cultures is hardly of sufficient significance to compensate for the effort involved. There is one outstanding conclusion from all this work, namely, the lack of any very definite, distinct, and constant bacteriological activity of the samples of one type that is not to a considerable extent shared by the samples of the other types. There are tendencies in certain types with regard to bacteriological activity which show that some of the types as a whole are more or less distinct from one or more of the others.   .

Ammonification.—The amount of ammonia produced from dried blood varies to a great extent. The Altamont samples gave between 10 and 33 mg. nitrogen as ammonia; the Diablo samples gave between 7 and 26 mg., and the Hanford samples gave between 35 and 72 mg. The Altamont and Diablo types are thus seen to be about alike in their low ammonifying power, as compared with the higher ability of the San Joaquin types and still greater ability of the Hanford types. And since there are somewhat greater variations between the types than between the samples of a given type, the ammonifying power may be significant.

Nitrogen fixation.—The two heavy types, Diablo clay adobe and Altamont clay loam, show no characteristic differences, while the two lighter types show considerable differences. As a whole the types are different one from another, yet the variations within the type are sufficient to prevent any statement that the rate of nitrogen fixation is a function of the type as determined in the field, or vice versa.

Nitrification.—The nitrification data are the most puzzling. The figures are extremely variable within a given type; the erratic way

in which the Hanford samples behave is not paralleled by any other type. There are certain ways in which the types are distinct:

The nitrification of the soil's own nitrogen as compared with the soil's action upon added nitrogen is in some degree separate for each type. The San Joaquin samples nitrified their own nitrogen to a greater degree than they did the nitrogen added to the soil.

The relative nitrification of the several nitrogenous materials (dried blood, cottonseed meal, ammonium sulfate) is in some measure distinct for the several types. The Diablo, Altamont, and San Joaquin types show ammonium sulphate to be nitrified the best, cottonseed meal less, and dried blood still less. The Hanford samples show cottonseed meal to give the highest percentage of nitrates, with dried blood less, and ammonium sulfate still less.

When any one soil is compared through the three sets of determinations there are no apparent similarities. The Hanford type shows the greatest bacterial activity, while the San Joaquin shows less, with the heavier types showing sometimes greater activity and sometimes less than that of the San Joaquin.

Work in Other States

In connection with the original chemical work reported in this paper, there should be mentioned the large amount of work done in a number of states on the analysis of the types of soils as mapped by the Bureau of Soils. Apparently, these analyses have been made without any question as to the validity of the existing subdivisions into types. The various analyses have been reported with some comment, but that which does appear usually deals with the "adequacy" or "inadequacy" of the plant food present. Blair and Jennings[36] present a large amount of data on chemical composition, some of which on rearrangement show interesting relationships (table 85). From the data the four series of soils with the largest number of analyses were selected (see following table). Under each series there are from 2 to 4 soil types, and from 2 to 6 analyses under each type. The averages from each type are tabulated, also the averages of all the types within the series. This is both for the strong acid extraction and the fusion methods of analysis for significant plant food elements. There are no doubts but that each series of soils shows characteristic chemical peculiarities, peculiarities which are to a great extent con-

[36] The Mechanical and Chemical Composition of the Soils of the Sussex Area, New Jersey, Geol. Surv. N. J., Bull. 10, 1910.

TABLE 85

	Dutchess			Dover			Gloucester				Chenango		Dutchess	Dover	Gloucester	Chenango
	Loam 6	Loam (shaley phase) 4	Shale loam 5	Loam 3	Loam (light phase) 2	Stony loam 3	Loam 5	Sandy loam 3	Stony loam 4	Stony sandy loam 4	Fine sandy loam 2	Loam 2				
Insoluble	82.82	80.07	75.95	86.93	86.87	86.66	84.55	84.00	84.19	84.11	89.53	89.74	....	....	....	....
SiO_2	.05	.062	.06	.05	.065	.033	.05	.03	.07	.04	.07	.06	....	....	....	....
K_2O	.28	.315	.34	.203	.13	.170	.21	.14	.205	.13	.125	.265	.31	.17	.17	.19
Na_2O	.083	.057	.074	.07	.055	.057	.08	.10	.11	.11	.10	.110	.071	.061	.10	.10
CaO	.08	.107	.13	.13	.24	.153	.26	.45	.19	.35	Tr.	.10	.106	.174	.31	.05
MgO	.68	.910	1.00	.51	.61	.510	.64	.52	.57	.43	.45	.465	....	....	....	....
Mn_3O_4	.04	.065	.05	.06	.045	.015	.06	.07	.03	.06	.045	.07	....	....	....	....
Fe_2O_3	3.05	3.91	4.49	2.67	2.33	2.32	2.50	3.76	2.99	3.68	1.96	2.42	....	....	....	....
Al_2O_3	4.96	5.70	6.73	3.09	3.57	3.89	4.22	3.79	4.01	4.20	3.09	3.06	....	....	....	....
P_2O_5	.135	.186	.137	.113	0.46	.077	.109	.156	.126	.152	.139	.114	.153	.217	.136	.126
SO_3	.065	.06	.06	.	.....	.040	.06	.045	.054	.06	.....	.....	....	....	....	....
CO_2	.038	.034	.053	.025	.035	.035	.04	.075	.075	.05	.023	.042	....	....	....	....
Volatile	7.67	6.21	11.06	6.21	5.32	6.117	7.27	6.15	7.44	6.61	4.54	3.73	....	....	....	....
Totals N	.161	.173	.213	.145	.138	.112	.150	.131	.174	.139	.094	.085	....	....	....	....
Totals C	1.82	1.877	2.43	1.54	1.45	1.42	1.59	1.31	2.27	1.72	1.175	.854	....	....	....	....
Totals K	1.44	1.68	1.606	2.46	2.75	1.79	2.58	3.06	2.22	2.53	.96	1.30	1.57	2.33	2.59	1.13
Totals Na	....	....	....	.60	.98	.50	1.43	.186	1.27	1.82	.635	.65	.17	.89	1.59	.65
Totals (P_2O_5)	.16	.215	.157	.134	.168	.091	.129	.175	.143	.174	.165	.131	....	.13	.15	.15

stant throughout the several representatives of the type. In some cases, the differences or similarities are more clearly seen in the total analyses, and in other cases, they appear in the acid analyses and not in the fusion analyses. Within any series the variations between analyses of any one type are about the same as the variations from type to type. There are many other papers[37] which provide material for similar comparisons.

A paper by Van Dyne and Ashton[38] reports chemical analyses for lime, phosphoric acid, potash, and nitrogen on the samples collected in the course of the survey of Stevens County, Washington. Though sometimes there is a much greater range within a type than between types, in a general way the analyses for any one type agree quite well. As a whole the chemical analyses seem to show that the field criteria are also a basis for grouping soils into certain chemical groups. It should be mentioned that the work of Blair and Jennings, also that of Van Dyne and Ashton, deals with individual areas, and not with samples from several scattered areas. The work of Fraps and Williams, and the original work here reported represent scattered areas.

The Greenhouse Cultures

By far the most interesting results were obtained in the pot culture work. It is realized that there are variations in the physical nature of the samples of a given type, yet since these samples were collected with considerable care by one familiar with field classifications, the samples so selected should be fairly representative of the type. It is probable that if all the soils in each of the types used were exactly the same in texture, i.e., if the mechanical analysis showed the same results for the several soils, the crops produced on the several soils of a type would be less divergent in appearance or weight. Yet it is not at all likely that the crops would be the same. Pot cultures presume that the conditions in all the pots can be kept uniform, but this is obviously impossible. Greenhouse work is subject to many interfering factors. Nevertheless, the results are believed to be significant,

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[37] Williams, and others, Report on the Piedmont Soils, North Carolina Dept. Agr., Bull. 206, 1915.

Fraps, G. S., Composition of the Soils of South Texas, Texas Agr. Exp. Sta., Bull. 161, 1913; Composition of the Soils of the Texas Panhandle, *ibid.*, Bull. 173, 1915.

[38] Van Dyne and Ashton, Soil Survey of Stevens County, Washington, Field Operations, U. S. Bur. Soils, 1913, pp. 2165–2295.

despite the large correction that the consideration of the probable error might introduce.

The differences in the crop producing power of the soils are very marked in the Diablo clay adobe, where the second crop, as well as the first, shows evident variations in the ability to support a crop. In the Altamont clay loam the second crop almost loses the variations seen in the first crop from pot to pot. The samples of both types seem to show one thing in common—the approach of the several samples toward a uniform ability to produce crops, as the soils are kept for longer periods under the same conditions. The Hanford soils did not show, with the several crops, the parallelism in the fertility from crop to crop as did the Diablo and Altamont soils. Some soils produced good crops of grain and poorer crops of legumes, others did the opposite. The low nitrogen content in this type seemed to be a limiting factor. This would account for the variation between the grain and the leguminous crops. Also, the presence, or absence of *Bacillus radicuola* inoculation in this connection might greatly affect the total crop produced.

There does not seem to be much doubt but that the soils of the several types compared in this way are not the same, though they are in certain respects similar.

The Place of Soil Classification.—With all these evidences that the soils within the several types are not closely similar. though they are classified the same by the Bureau of Soils. what conclusion is one to reach as to the value of such a classification? If it were true that there were no appeal from the findings of such laboratory and greenhouse determinations as these, and that these determinations were a final proof of the fertility or infertility of a soil, obviously there would be but one thing to do—discard all such field classifications as useless. But the writer is one of a great many soilists who are not willing to rely on laboratory or even greenhouse results for an *absolute* determination of fertility, and for the grouping together of soils into a workable classification. Not enough is definitely known as to the meaning of such findings, though there are certainly many valuable points shown by laboratory analyses.[39]

As examples of the value of natural classifications we may consider those of botany, zoology, or mineralogy. If available, a wholly satisfactory classification of soils would be equally useful. The appre-

[39] Jordan, W. H., Measurements of Soil Fertility, New York Agr. Exp. Sta., Geneva, Bull. 424, 1916.

ciation of this is shown in the many systems of soil classification that have been proposed.

Despite the foregoing facts that have been obtained showing the divergent properties of different samples of one type presumably alike, yet it must be admitted that soil surveys, even such as are no more refined than those of the Bureau of Soils, have considerable value for field use.

It is felt that the additional effort required to modify the practices of the Bureau of Soils in the mapping and classifying of soils would be more than justified by the increased accuracy and usefulness of the maps. To point out some of the causes of the present practices and to give suggestions for possible methods of improvement, the following discussion of the Bureau of Soils methods has been prepared.

Discussion of the Bureau of Soils' methods.—The methods of mapping and classifying soils, as devised and used by the Bureau, have resulted from some definite and important considerations.

1. The necessity for keeping down the cost of surveying and mapping prevents the use of laboratory and culture methods in the study of the soils classified, even if it were not for the fact that one of the outstanding policies of the Bureau apparently denies the validity of such studies in the classification of soils. This does not include the mechanical analysis of soils, which is not a separate laboratory determination, but a method of checking the field man's decision as to the texture. It should also be added that some of the reports as published in the Field Operations of the Bureau of Soils, for 1913, show the subdivision of the soils into two groups based upon the CaCO content. Keeping down the cost has also prevented the use of sufficient time to map the soils correctly, even according to the criteria admittedly of value in the system adopted. Many of the other methods of classifying and mapping soils, even if applicable to most of the agricultural regions of the United States, would be absolutely out of the question on account of cost.

2. The large and widely diversified area of the United States, and the attempt to map representative areas in various parts of the country, early led to difficulties. There seemed to be a lack of understanding as to what criteria to use in the classification of the soils. Recently, some of the areas first mapped in the state of California have been resurveyed. The texture, series, and province differences of the early mapping seem not to have been clear. For example, we may con-

sider the differences between the older and the recent survey of two localities east of Los Angeles. The notes were made by C. J. Zinn, a member of the party which made the recent survey:

Locality A—About 15 square miles with Eaton Wash on the west, center of Monrovia on the east, mountains on the north, and a line about 3 miles south of mountains as the south boundary. The old survey[40] has four types of three series and two miscellaneous types: San Gabriel gravelly loam, San Gabriel gravelly sand, Placentia sandy loam, San Joaquin black adobe, and Riverwash and Mountains. The new survey (1915, unpublished) has 13 types of 6 series and 3 miscellaneous types: Hanford stony sand, gravelly sand, loam, sandy loam, fine sandy loam, and sand; Tejunga stony sand; Zelzah loam and stony loam; Placentia loam, Holland loam, Chino loam and silt loam. The miscellaneous types are Rough Mountain land, Rough Broken land, and Riverwash.

Locality B—In the city of Pasadena, comprising about 3.5 square miles, with the southwest corner at the center of the city. The old survey[41] shows San Gabriel loam occuping about 0.6 of the area, San Gabriel gravelly sand about 0.3, and Placentia sandy loam about 0.1. The new survey (1915, unpublished) shows Zelzah gravelly loam occupying about 0.9 of the area, Zelzah loam about 0.1, with a very small body of Holland loam. The older survey showed a recent alluvial soil where the recent one shows an old valley filling soil.

Besides these errors (detected as such by the practical man, who might attempt to use the soil maps in the field) there are in addition those of another nature which were the source of much criticism in the earlier history of the survey—the so-called "procrustean classification" criticism of Hilgard.[42] Due apparently to an insufficient study of the soils of the United States, there was the attempt to classify in the same series soils of widely differing properties—differences of an important nature being ignored.

At the present time there is an increasing tendency toward limiting series groups of soils to a more or less definite climatological region. In this connection see the later changes in the correlation of many soils.[43] These changes tend to limit the geographic range of the series, and make these series narrower and more exact. Moreover, it is understood that as the knowledge of the soils has increased, the changes in correlation have been proceeding rapidly since the above list was issued. This indicates that as the facts accumulate the "procrustean classification" criticism is losing its force.

[40] Field Operations of the U. S. Bur. of Soils, 1901, San Gabriel sheet.

[41] *Ibid.*

[42] Hilgard, E. W., and Loughridge, R. H., Proc. Second Intern. Agrogeol. Conf., Stockholm, 1910, pp. 228-29; Hilgard, E. W., U. S. Office Exp. Sta., Bull. 142 (1904), p. 119; Hilgard, E. W., Proc. First Intern. Agrogeol. Conf., Budapest, 1909, pp. 52-54.

[43] U. S. Bur. Soils, Bull. 96, 1913.

3. There was a lack of trained men early in the work. This was to be expected. As has been shown, the early surveys were very crude in certain places. It must be added that some of the errors and omissions made in the more recent maps are not due to a lack of training, but to the carelessness of the field men with respect to details.

4. The policy of the Bureau has been to recognize the physical characteristics of the soil as factors in fertility to the virtual exclusion of the chemical or biological factors. Therefore the use of physical criteria is necessary. Besides, the criteria must be such as can be applied in the field, and are: (1) color, (2) texture, determined by rubbing between the thumb and finger, (3) structure, (4) nature of subsoil, (5) presence of hardpan, (6) height of water table, (7) presence of alkali, (8) topography, (9) physiographic form and hence mode of formation, and (10) source of material (sedimentary, igneous, or metamorphic rocks). Humus, and the presence or absence of appreciable quantities of lime, also the reaction of the soil (acid or alkaline) are frequently guessed at. These criteria are practically the only ones that can be applied in field work. It is believed that these same criteria indicate the chemical nature of the soil, though there has been no attempt to correlate some of the factors. However, the original work reported in this paper would indicate that the chemical nature is not the same, of soils classified the same by the Bureau of Soils criteria.

5. The desire to limit the number of groups of soils is a wholly sound one. In discussing the problems of classifying soils there should always be kept in mind the fact that some of the problems are not very different, fundamentally, from some of the problems that have been causing perplexity among biologists for a long while. The tendency, as seen in some of the recent surveys, to make the series more inclusive and to introduce the term, phase, is heartily commended. By making the series broader there will be less difficulty in placing a soil in its proper group. The phase will take care of many of the series differences between area and area.

6. It seems certain that if there were more emphasis placed upon the inspection of the area, during the progress of the field work and after its completion, there would be a much closer approach to accuracy throughout the map and report. At the present time the field man is not closely checked up. The careless or indifferent worker can map more or less as he pleases, especially in the out-of-the-way places.

7. Whether the soil survey should include more than a simple classification of the soils or not, is an unsettled question. It is thought hardly possible that in a soil survey the field man could handle all the phases of an agricultural survey of an area, when his energies should be fully employed in the classification of the soils. It is believed that the place of the survey, in this country at least, is to handle the *classification* of the soils, leaving the study of the remaining factors largely to other specialists, who would use the soil survey as a basis.[44] But to make the soil maps of more general use for such work, they must be more accurate. These maps never can become the basis of other agricultural studies as long as many experiment station workers ridicule them. Hence, the ultimate effort of the survey should be toward better work, rather than covering a wide range of agricultural studies.

8. There is not the incentive to make as many separations of the soils in the field, as the field man might think best, because frequently the feeling of the editors is that there would be too many small bodies of soil shown on the manuscript maps which would not warrant the additional cost of publication.

In conclusion, the Bureau of Soils' system has much to commend it as a field method, and the resulting maps and classification are believed to be of distinct value. It is felt that a more general understanding of: (1) the limitations under which the maps, the earlier ones especially, have been made; (2) the difficulties under which the field work is at present carried on; (3) the meaning of the correlation of soils; and (4) the general policy of the Bureau of Soils would give people more sympathy with their work.

44 Fippin, E. O., Proc. Amer. Soc. Agron., vol. 1 (1908), pp. 191–97.

SUMMARY

Presumably typical samples of four soil types were collected for laboratory and greenhouse study from widely distributed localities in the state of California. The field appearance of each sample was usually sufficient to warrant the classification as it exists.

PHYSICAL RELATIONS

1. The mechanical analysis by the Hilgard elutriator shows that the soils of a given type are in some cases quite divergent from each other in their content of certain of the sizes of particles. The mechanical analysis by the Bureau of Soils method shows that 6 of the 24 soils were not true to their type names, and that of those soils within the type there is considerable variation.

2. The moisture equivalents for the several types show distinct enough values to substantiate the field separation.

3. The hygroscopic coefficients vary widely within each type and the types are not shown to be distinctly different by this criterion.

CHEMICAL RELATIONS

1. The total nitrogen averages vary markedly from type to type, with the Altamont clay loam containing three times that in the San Joaquin sandy loam.

2. The average humus content of the San Joaquin samples is about half that of the other types. The variations in the humus content between the types are small, considering the diverse nature of the types and the large range in the amount of humus within the type.

3. The loss on ignition shows a considerable variation within the type and no significant distinction between the four types.

4. The average total calcium content of the types is distinct, though the wide range within each type minimizes the significance of the variation in the averages.

5. With regard to magnesium, the types are neither distinct nor are the soils within the type closely similar.

6. The average phosphorus content of the types is distinct, though the ranges within the several types frequently overlap.

7. The total potassium results do not show the types to be distinct nor the soils within a type closely similar.

Bacteriological Relations

1. The ammonifying power shows rather larger variations from type to type than between the samples of a type.

2. The nitrogen fixation data do not show characteristic differences for the several types.

3. Regarding nitrification as a whole there may be a greater divergence between the samples of a type than between types. The relative nitrification of the soil's own nitrogen varies with the type, as does the relative nitrification of the several nitrogenous materials added.

Pot Cultures in the Greenhouse

In addition to the effect of the probable error, the impossibility under the conditions herein described of growing the same crops on all the soils, during the same season of the year in the greenhouse, prevents close comparisons between the types, or between the first and second crops on a given soil. The comparison of several samples of a given soil type and the comparisons of various soil types, according to the previously outlined greenhouse methods show that:

1. Different representatives of a given type are not the same in their ability to produce crops.

2. The arrangement of the samples of a given type according to their fertility may or may not vary with the special crops used as the indicators.

3. The types are distinct with respect to their fertility, considering their average production.

Therefore it is concluded that with regard to the 24 soils of 4 types examined, all soils mapped under a given name by the Bureau of Soils method may or may not be closely similar, depending upon the criteria used. The greater number of the criteria show the soils of a type to be not closely similar, and the types to be but litle differentiated from each other.

In connection with the results of the author's study of the soils, there is given an historical sketch of the development of soil classification and mapping, also a discussion of certain of the methods employed by the Bureau of Soils of the United States Department of Agriculture. It is pointed out that despite its defects, the work of the Bureau of Soils is of value, and is practically the only type of soil classification and mapping possible under the conditions imposed.

APPENDIX A

METHODS AND TECHNIQUE

COLLECTION OF SAMPLES

There was difficulty in finding types that would meet the requirements of wide distribution and of differing from one another as to series as well as texture. The types chosen were:

Diablo clay adobe, a residual soil.

Altamont clay loam, a residual soil.

San Joaquin sandy loam, an "old valley filling" (*old* alluvial soil).

Hanford fine sandy loam, a recent alluvial soil.

The first task was the collection of the samples of soil for study in the laboratory and in the greenhouse. Of course, there were kept in mind the errors and difficulties involved in the collection of representative samples. The selection of the localities in which to collect samples was frequently made in consultation with the persons who had originally mapped the areas under the Bureau of Soils. This was done so that the soil chosen might as nearly as possible represent what the surveyor had in mind as characteristic of the type within the area. It was to be expected that the ideal type which one man would use as a guide as he did the mapping in one area would not always be identical with that which another man might use in mapping another area, despite the aid of the inspector in keeping the ideal types of the field men as nearly alike as possible. Some of the accompanying index maps, showing the places where the soil samples were collected, are duplicates of the same locality. As the dates show, one is a portion of a less recent, and the other of a more recent survey. In many cases the index maps have been copied from the manuscript maps, a number of surveys in this state not yet being published. For a discussion of the differences in these maps, see below the section on The Criticism of the U. S. Bureau of Soils Method of Surveying.

Not only were the field men questioned about the locality, but as nearly as possible an exact designation was obtained on the soil map itself. In the collection of some of the samples the writer had the good fortune to have the assistance of the man or men who actually mapped the soils in question. Sometimes there was no trouble at all in locating a typical body of the soil where a sample might be taken. On the other hand, as in the case of the collection of the Hanford fine sandy loam from Woodbridge (nos. 15 and 16), more than two hours were spent in driving about, trying to find a place that seemed a typical fine sandy loam. Experience shows that the personal equation in field work is very important and is hard to control.[45]

No special attempt was made to obtain virgin soil, for the types of soils that had been selected for study were mainly agricultural, and most of the soils have been at some time under cultivation, if they are not now. Also, there has been little, if any modification of the agricultural soils by the addition of fertilizers. Hence the small tracts of the Hanford fine sandy loam, for instance, that are still virgin are largely non-agricultural, waste land areas, and would not illustrate the properties of the type as a whole. Not so large a part of the San Joaquin sandy loam is under cultivation now, though almost all of it has been farmed to grain in the past. The two minor types studied, the Altamont clay loam and the Diablo clay adobe, being of residual origin and occupying rolling to hilly or mountainous land are also not very extensively farmed. The topography is the limiting factor in most cases.

[45] Fippin, E. O., Practical Classification of Soils, Proc. Amer. Soc. Agron., vol. 8 (1911), pp. 76–89; Increasing the Practical Efficiency of Soil Surveys, Proc. Amer. Soc. Agron., vol. 1 (1907–1909), pp. 204–06.

The ideal way to collect a representative sample of soil for laboratory studies is to make a number of borings scattered about the field or fields, so that the sample will approximate an average. But in the case of collecting the samples for this study it was considered best not to attempt such a procedure, for the reason that it was desired to have the samples for the greenhouse work and for the physical, chemical, and bacteriological studies, come from the same lot of soil. The collection of such a large amount of soil, about 250 pounds in all, from a number of places about the selected field would be very tedious. Hence as nearly a typical place as possible was selected, close to a wagon road, in order that the samples could be transported readily. Care was used that the location be far enough out into the field to allow the sample to be representative of the conditions in the field.

The subsequent procedure was as follows: The selected spot was cleared of grass or other surface material or accumulation that did not belong to the soil. A hole was dug, usually one foot deep (the depth depending entirely upon the nature of the surface soil and any noticeable changes toward the subsoil), and big enough to give sufficient soil to make up the greenhouse sample of from 225 to 250 pounds. The soil was shoveled directly into tight sugar or grain sacks, no attempt being made to mix the sample at this time. Some sacks of the soil would contain more of the surface material, and others more of the lower portion, but a later thorough mixing and screening at the greenhouse gave a uniform sample. After the large sample was collected, the hole was usually dug two feet deeper, giving a hole three feet deep. One side of this hole was made perpendicular, and from this side the small samples were collected. The A, B, and C horizons were marked off on this wall, and the samples collected by digging down a uniform section of the designated portion, using a geologic pick and catching the loosened material on a shovel. About ten pounds of soil were so collected, and placed in clean, sterile canvas sample sacks. Care was used not to contaminate the samples, so that the bacterial flora might remain nearly unaltered. It seemed impracticable to attempt to collect the laboratory sample under absolute sterile conditions, especially since some of the deeper (B and C) samples were obtained by means of the soil auger. When the auger was used to collect the samples from greater depths the boring was done from the bottom of the hole made in collecting the larger sample. The size of the laboratory sample required the boring of five or six holes with the usual 1.5 inch soil auger. The laboratory sample of the first foot, or the A sample, was always collected from the side of the large hole. Notes regarding the sample, field condition, the place of collection, together with photographs and marked maps are given in appendix B.

As described above, the soils were collected in separate portions from the surface to the 12 inch, from the 12 to 24 inch depth, and from the 24 to 36 inch depths where there were no abrupt or marked changes in the color, texture, or the like, as in the Hanford fine sandy loam. But since in some cases, as most frequently in the San Joaquin sandy loam, the samples do not represent the first, second, or third foot depths, as the case might be, the term, horizon, has been used. Horizon A indicates the surface sample, horizon B the second sample, and horizon C the third sample.

LABORATORY PREPARATION OF SAMPLES

The large samples were stored in the greenhouse until ready for use. The laboratory samples were allowed to remain in the sacks until air dry, when they were passed through a 2 mm. screen. This was a difficult matter, with the heavy soils, as well as with the heavy subsoils of the San Joaquin sandy loam. Cautious use

of the iron mortar was necessary to supplement the rubber pestle.[46] The samples were thoroughly mixed after screening, when they were weighed and placed in sterile containers—glass jars and large bottles. Precautions were taken as far as possible to avoid contamination of the samples during this preparatory process. The screens, mortars, scoop, and pans were flamed out between samples. Obviously contamination could not be avoided absolutely without too great a prolongation of the work.

The material not passing the 2 mm. screen was subsequently washed on the screen, with a stream of water to remove the finer material. The residue not passing the screen by this treatment was dried and weighed. It seemed unnecessary to adopt elaborate precautions, like those described by Mohr,[47] to obtain the exact quantities.

MECHANICAL ANALYSIS

The Hilgard elutriator was used for the purpose of making the mechanical analysis of the samples (surface horizon only). For the purpose of this work the method described by Hilgard[48] has been modified in several respects. The preliminary preparation by sifting through the 2 mm. sieve in the dry state, and through the 0.5 mm. sieve by the aid of water was used. One hundred grams was sifted with the 0.5 mm. sieve, and the fine material plus the water was evaporated to dryness on the water bath. The dry material was broken up and from this the samples were weighed out for the analysis.

The samples were not disintegrated by boiling, since it was believed that such treatment would affect the "colloid" content of the sample. Instead, the samples were shaken with water in sterilizer bottles for three hours, similar to the treatment preparatory to the mechanical analysis by the Bureau of Soils method. However, not boiling the samples caused more work later.

The colloidal clay was removed by placing the previously shaken sample in a large precipitating jar and stirring up with several liters of distilled water. (Distilled water was used throughout the analysis.) The quantity of water was not important, but rather the depth of the suspension, which was 200 mm. After allowing to stand for 24 hours the supernatant turbid water was siphoned off, when the residue in the bottom of the jar was again stirred up with water and the clay again allowed to settle out of a 200 mm. column. This was repeated until the supernatant liquid contained practically no material in suspension after standing for 24 hours. The clay suspensions were placed in large enamelware preserving kettles, and the solutions reduced in volume by boiling. The final evaporations were carried on over the water bath, so as to avoid too high a temperature.

A large portion of the finest sediment (0.25 mm. hydraulic value) was removed as follows: After the greatest portion of the clay had been removed by the 24 hour sedimentation and decantation, the sample was placed in a 1 liter beaker and stirred up with sufficient water to make a 100 mm. column. After standing 6 to 8 minutes the suspended material was decanted off. This was repeated until the supernatant solution was practically clear. The entire time for these decantations usually occupied 2.5 or 3 hours. The decanted material was allowed to stand for 24 hours, as before, and the 200 mm. column decanted as with the original clay suspension. This was continued until the clay was practically all removed.

[46] Hilgard, Calif. Agri. Exp. Sta., Circ. 6, June, 1903.
[47] Bull. Dept. Agr. Indes Neerland., no. 41, 1910.
[48] Calif. Agr. Exp. Sta., Circ. 6 (1903), pp. 6–15; see also Wiley, Agricultural Analysis, vol. 1 (1906), pp. 246–62.

The residue constituted the main portion of the 0.25 mm. hydraulic value separate. The residue from the 6 to 8 minute decantation was placed in the elutriator, and separated by the usual method into the various sizes. Since, however, the sample was not prepared by boiling previous to the separation of the clay, the clay was never as thoroughly removed from the coarser particles and the finer aggregate particles were not completely broken down. Hence when the sample was placed in the elutriator and subjected to the violent agitation of the stirrer an appreciable amount of clay passed off with the finest separate. Therefore, instead of allowing the water to return to the carboy from the settling bottle, during the running off of the finest separate, the following procedure was employed: The water was run into precipitating jars and allowed to stand for 24 hours, and the clay water was then decanted off and boiled down with the other clay water.

A further modification of the Hilgard method was found advisable after the change from the large elutriator tube to the small one, preparatory to running off the coarser separates. The mechanical defects in the elutriator always allowed for the collection of a portion of the sample in crevices where the stream of water could not reach to carry off the particles. Hence, when the large tube was removed, and cleaned, there was found an appreciable amount of the finer sediments that had not passed over. These were all added to the small tube of the elutriator, and the additional material of the smaller sizes run off, using an hour or so for each size. This seemed a better method than the separation of such sediments by the beaker method, as was done by Dr. Loughridge.

The separates, after decanting most of the water, were dried first on the water bath and later in the drying oven at 100°C–110°C and weighed. All of the determinations were made on the water free basis.[49]

ADDITIONAL PHYSICAL DETERMINATIONS

Upon the surface or A horizon samples of the 24 soils considered in this study additional physical determinations were made by the Division of Soil Technology, through the courtesy of Professor Charles F. Shaw. These determinations were of the mechanical analysis by the Bureau of Soils method,[50] of the moisture equivalent by the Briggs and McLane method,[51] and of the hygroscopic coefficient according to Hilgard's method.[52]

CHEMICAL METHODS

At first the chemical work was based upon the "strong acid extraction" method, so well known through the work of Dr. Hilgard.[53] There are some very pertinent objections, as well as advantages, to the method of acid extraction for the purpose of comparing soils among themselves.[54]

In the analysis 2.5 gram samples, air dry, were used throughout. The acid extraction results are not included in this paper.

[49] The writer wishes to emphasize the tedium of the elutriator process, and to advise strongly against the use of the apparatus for the comparison of the soils as to texture. The elutriator is excellent from a theoretical point of view, but the results do not at all warrant the extravagant use of time in the laboratory that the apparatus requires.

[50] U. S. Bur. Soils, Bull. 84, 1912.

[51] *Ibid.*, Bull. 45, 1907; Proc. Amer. Soc. Agron., vol. 2 (1910), pp. 138–47.

[52] Calif. Agr. Exp. Sta., Circ. 6 (1903), p. 17; Soils, pp. 197–99.

[53] Calif. Agr. Exp. Sta., Circ. 6 (1903), pp. 16ff; Soils, pp. 340ff.

[54] See Hissink, Intern. Mitt. für Bodenkunde, vol. 5 (1915), no. 1.

The sodium peroxide fusion method[55] was carried out on the two larger series of soils, the Hanford and the San Joaquin. The elements sought were phosphorus, calcium, and magnesium. Five gram samples, air dry, were used throughout. The general method of analysis, as set forth by Hopkins, was employed, though there were a number of refinements used to increase the accuracy of the results. As such might be mentioned the double precipitation of the iron, aluminum, and phosphorus.

Phosphorus was determined volumetrically, according to the method of Hibbard.[56]

Total nitrogen was determined by the modified Gunning-Kjeldahl method, using ten gram samples.

Loss on ignition was determined upon the 10 gram, air dry samples that were used for the determination of the hygroscopic moisture of the samples used in the chemical analysis. The soils were ignited in a muffle furnace to constant weight.

Humus was determined by the Grandeau-Hilgard method,[57] using 10 gram samples, air dry.

Potassium was determined by the J. Lawrence Smith method, using one gram samples.

BACTERIOLOGICAL METHODS

The only bacteriological methods employed were the determination by the tumbler or beaker method of the ammonifying, the nitrifying, and the nitrogen fixing powers of the soils.[58] All cultures were run in duplicate.

Ammonification tests were made using 50 grams of soil and 2 grams (4%) of dried blood. The checks were distilled at once, and the cultures kept in the incubator at 24°C–30°C for one week. (The incubator thermostat was unsatisfactory in its action, hence the variation in the temperature.)

The nitrifying power of the soil was tested as regards the soil's own nitrogen, dried blood, cottonseed meal, and ammonium sulfate. In the Diablo clay adobe and the Altamont clay loam 50 grams of soil were used, to which was added 1 gram (2%) of dried blood, or of cottonseed meal, or 0.1 gram (0.2%) of ammonium sulfate. In the case of the San Joaquin sandy loam 50 grams of soil were used, together with 1 gram (2%) of dried blood or of cottonseed meal, or 0.2 gram (0.4%) of ammonium sulfate. In the series run on the Hanford fine sandy loam 100 grams of soil were used, to which were added 1 gram (1%) of dried blood or of cottonseed meal or 0.2 gram (0.2%) of ammonium sulfate. It is to be regretted that the several series could not all be run on exactly the same basis as the Hanford series. But the small amount of stock soils of the samples of the earlier series precluded the use of larger original samples, not to speak of the impossibility of repeating these series. The cultures were incubated for four weeks at 24°C–30°C. At the end of this period the cultures were dried in the oven at about 90°C and the nitrate content determined by the phenoldisulfonic acid method according to the modifications of Lipman and Sharp.[59]

Nitrogen fixation. For this determination uniform quantities of soil were used throughout—50 grams, to which was added 1 gram of mannite. These cul-

[55] Hopkins, Soil Fertility and Permanent Agriculture, pp. 630–33; Hopkins and Pettit, Soil Fertility Laboratory Manual (Boston, Ginn, 1910), pp. 42–45.

[56] Jour. Ind. Eng. Chem., vol. 5, pp. 999–1009.

[57] Calif. Agr. Exp. Sta., Circ. 6 (1903), p. 21.

[58] Burgess, P. S., Soil Bacteriology Laboratory Manual, Easton, Pa., The Chemical Publishing Co., 1914.

[59] Univ. Calif. Publ. Agr. Sci., vol. 1 (1912), pp. 21–37.

tures were incubated for four weeks at 24°C–30°C, at the end of which time bacterial action was stopped by drying in the oven for 24 hours. Subsequently, the samples were broken up in a mortar, and 10 grams weighed out for the determination of the total nitrogen.

<div align="center">POT CULTURES IN THE GREENHOUSE</div>

The large samples of the surface foot of soil were stored in the greenhouse until used. The preparation of the samples was in most cases as follows: The sample was placed on a large table and screened through a quarter inch sieve. This treatment of screening was attempted with the Diablo clay adobe and the Altamont clay loam, but was abandoned as practically hopeless. The samples of these two types had been collected in the late summer, when the ground was very hard and dry, hence the clods defied any efforts to break them up. As an alternative the samples were as thoroughly mixed as possible and weighed out into the pots. Several waterings during a week, together with carefully breaking up the lumps by hand, rendered the soils finely divided enough to permit the planting of the seeds. The Hanford and San Joaquin types were readily screened.

All the soils were weighed out into nine inch flower pots. In most cases the pots had been previously paraffined. Care was taken to clean the pots thoroughly, as far as surface material was concerned; many of the pots were scrubbed with a brush and water. All previously used pots were examined to exclude the use of such as had formerly been used for soils containing high percentages of soluble salts, but such examination was not always successful in eliminating the undesirable pots, as was afterwards evident. In the Diablo, Altamont, and Hanford soils the quantity of soil used was five kilos per pot. In the San Joaquin soils six kilos were used.

Enough soil was collected to fill eighteen pots. This would allow for the arrangement of six sets of triplicates of every sample; and the planting of a different crop in each of the sets would allow for the growing simultaneously of six different crops on every soil. For example, there were placed together in the greenhouse and considered as a unit in the culture work the series of the Diablo clay adobe, including three pots of the sample taken from San Juan Capistrano, three from that taken near Los Angeles, three from that of the San Fernando valley, and lastly three from the sample taken in the Danville region. This group of pots was planted to oats, barley, bur clover, or any one other crop. The pots were kept together in the greenhouse, that the conditions for each one in the set would be as nearly uniform as possible, for even a slightly different location in the greenhouse was found to affect the crop appreciably. The other five sets of pots were similarly treated. No fertilizing materials were added to any of the soils. All were used in their normal condition. The aim was to compare the crop producing power of the representatives of a given type of soil from various localities.

Several crops were grown, as the desire was to get a series of plants that would grow well under greenhouse conditions, and act as indicators. It was known that barley was about the best crop to use, but supplementary plants were desired. Barley, wheat, oats, rye, millet, milo, cowpeas (black eye beans), soy beans, beans (small white), bur clover (*Medicago denticulata*), sweet clover (*Melilotus indica*), and oats and bur clover in combination were tried. Some were a marked success under greenhouse conditions, and others were practically total failures; the better crops were given by barley, soy beans, bur clover, and millet. Sweet clover gives excellent results. This wide range of varieties of plants was

necessary because of the fact that it was desired to grow two crops a year on the soils. The winter crops will not do well in summer, and vice versa, even though the summers in Berkeley are relatively cool, and though the greenhouse was whitewashed during the summer months.

The seed was obtained in most cases from the Division of Agronomy of the Department of Agriculture of the University of California. Such varieties as were not available from this source were obtained from the commercial seed houses in San Francisco.

Usually the seed was planted directly in the pots, using sufficient seed to be sure that enough would germinate and grow to give the desired number of plants per pot, usually six. After the plants were well established, and before there was any crowding in the pots, the plants were thinned. In some cases an insufficient number of plants germinated to give the desired number per pot. Difficulty was found in getting the soy beans and cowpeas to germinate, especially in the heavier soils. This was overcome by sprouting the seeds in an incubator and planting them when the radicle was half an inch long or more. An excellent stand was thus obtained.

No actual measurements of the height of the plants, or the length of leaves were made in the greenhouse work. But photographs were taken, and in these photographs the attempt was made to secure representative records of the entire series, without photographing the crop in every pot. The usual procedure in the Altamont and Diablo series was to photograph two pots out of each set of triplicates, an attempt being made to select average, representative pots. In the large Hanford series one representative pot of each set of triplicates in each crop series was photographed, and three representative sets of triplicates were also photographed. Thus some of the pots appear twice, and allow of comparisons.

If any doubt be entertained as to the relative weights of the crops in the pots photographed as compared with those not so recorded, the relative weights of the crops may be easily obtained by referring to the tables of dry weights. In practically every case the pot label can be read from the photograph. The method of labeling is exemplified as follows:

    6   Soil sample no. 6 (Diablo clay adobe from Danville).

    W Wheat, first crop.

    2   Pot 2 of the triplicate set first planted to wheat.

    CP Cowpeas, second crop.

During the growth of the crops, notes were taken as to the relative growths and the general conditions of the plants.

When the crop had ceased growing it was harvested, whether or not it was mature in the sense of having set and developed seed. The plants from a given pot were put in a paper bag, labeled, and placed in the drying oven for 24 hours. The plants were weighed when dry and cool. If any mature seed was produced it was weighed separately.

Between the first and second crops the soil was allowed to rest from two to three weeks or longer. Each pot was emptied and the soil passed through a quarter inch screen before replacing in the pot. This broke up the lumps and removed most of the roots. The roots were not saved. The weight of the roots would have been interesting, but their recovery, especially from the heavy soils, would have involved careful washing, and the loss of much of the soil. It was thought that some washing would be necessary, even in the Hanford series, in order that the resulting figures might be at all accurate.

APPENDIX B

SOIL SAMPLE LOCATIONS

FIELD NOTES ON THE SOIL SAMPLES COLLECTED

No. 1—Diablo Clay Adobe

Location: A little over a mile east of San Juan Capistrano, Orange County. On the lower slopes of the hills to the south of San Juan Creek. Sample station is on a little shoulder running northwest, between Mr. Echenique's house and the fence following the road to Prima Deshecka Canada. Approximately one-quarter mile from the above house.

Soil: 0–12 inches—Dark gray adobe; much cracked.

12–36 inches—Soil becomes gradually lighter in color, approaching a light bluish gray mottled with brown.

36 inches—The subsoil becomes a silty clay loam in the lower depths.

History: The field was pastured up to and including 1906. From 1907 to date the field has been annually planted to barley. Data from Mr. Echenique, the owner. Sample collected August 19, 1917.

Depths of horizons:

1–A   0–12 inches.   1–B   12–24 inches.   1–C   24–36 inches.

No. 2—Diablo Clay Adobe

Location: One and three-quarter miles east of southeast of Eastlake Park, Los Angeles. Station is 0.7 mile by secondary road south of Pacific Electric railroad crossing, and 1.2 miles southeast of the Southern Pacific railroad crossing. Station is about 150 feet up the hill to the west of the road, in grain field, and 75 feet south of a 10 or 12 year old eucalyptus grove. The road, going south, emerges from the grove, and is then flanked by pepper trees.

Soil: 0–12 inches—Dark gray to almost black, but with a shade of brown rather than a bluish gray.

12–24 inches—Dark grayish brown clay adobe, becoming a little lighter with depth.

24–36 inches—Dark brown with soft, whitish fragments. Fragments probably the partially weathered parent rock, though no outcrops of the rock were seen in the vicinity. Previous to the collection of the sample, Mr. E. C. Eckman, who mapped the area as the Bureau of Soils representative, said in substance: ''We have no good Diablo in the area; the body I am directing you to is as good as any, but it is pretty brown.''

History: Property owned by Mr. Huntington. Farmed to grain the past 2 years; pasture previously. Data from the son of the tenant. Sample collected August 20, 1915.

Depths of horizons:

2–A   0–12 inches.   2–B   12–24 inches.   2–C   24–36 inches.

No. 3—Altamont Clay Loam

Location: 1.4 miles southeast of Walnut, Los Angeles County, on the shoulder of a low hill, about 200 feet east of the wagon road running south through the hills. The station was selected so that the texture was about right, for in a very short distance there were variations from a heavy dark clay loam or clay adobe to the light clay loams.

Soil: 0–36 inches—A medium textured brown friable clay loam. The soil column throughout was more or less filled with small soft whitish fragments, portions of the parent rock.

36 inches—The weathered parent rock was encountered.

History: A. T. Currier, owner. The field is in pasture, and has not been cultivated for forty years, to the knowledge of the ranch foreman. The soil is probably virgin. Sample collected August 20, 1915.

Depths of horizons:

3–A 0–12 inches.	3–B 12–24 inches.	3–C 24–36 inches.

No. 4—Altamont Clay Loam

Location: On a hillside a few feet above the Cahuenga Pass (Burbank road), near Oak Crest, Los Angeles County. Just a few feet from the U. S. Bureau of Soils station for the type in the San Fernando area. (For map, see the map under sample no. 25.)

Soil: 0–14 inches—A dark brown clay loam.

14–36 inches—A yellowish brown loam, grading into the weathered, thin bedded shales at about 36 inches.

History: Roadside, above the big cut on the road, probably never tilled. The surface is not so steep but that it could be well tilled; some of the soil in the immediate vicinity is cultivated to grain. Sample collected August 21, 1915.

Depths of horizons:

4–A 0–12 inches.	4–B 12–24 inches.	4–C 24–36 inches.

No. 5—Diablo Clay Adobe

Location: About ½ a mile north of Calabasas, San Fernando Valley, Los Angeles County. The station is some distance up the hill to the west of the road running north from the Calabasas store. The sample was collected near the top of the hill, to the northeast of the oak tree.

Soil: A dark gray to black typical clay adobe. Distinctly heavy. Digging was very difficult, the soil coming up in large, very hard clods. The soil was of about the same color and texture down to the bedrock at 26 inches. The bedrock is a heavy claystone or shale.

History: John Grant, Calabasas P. O., owner. The land has been dry farmed to grain. Presumably there had been no additions of fertilizing materials to the soil. Sample collected August 21, 1915.

Depths of horizons:

5–A 0–14 inches.	5–B 14–26 inches.	26 inches. Parent rock.

No. 6—Diablo Clay Adobe

Location: In Contra Costa County, ½ mile west of Tassajero; 6 miles east and a little south of Danville. Station about 150 feet up the hill to the south of the road, that is, about one-third of the way up the hill.

Soil: 0–34 inches—A black or dark gray clay adobe, moist at 10 inches.

34–72 inches—A dark grayish brown subsoil, becoming lighter below the third foot. No bedrock within the 6 foot section, nor was there any sign of any outcrop in the vicinity. The slope of the hill moderate, the exposure north. The sample was collected with the assistance of Mr. L. C. Holmes and Mr. E. C. Eckman, both of the U. S. Bureau of Soils. They pronounced the station typical.

History: Property owned by J. J. Johnson. The field has been farmed to grain for probably 60 years. Formerly the rotation was pasture one year, and grain one year; now the practice is grain two years, and pasture one year. Sample collected September 2, 1915.

Depths of horizons:
 6--A 0–12 inches. 6–B 12–24 inches. 6–C 24–36 inches.

No. 7—*Altamont Clay Loam*

Location: On the Mission Pass road, a little less than 2 miles south and a little west of Sunol, Alameda County. About 100 feet above the road, between wooden electric power poles nos. 92/30 and 92/31.

Soil: 0–34 inches—A medium brown clay loam, considered typical by Mr. L. C. Holmes and Mr. E. C. Eckman of the U. S. Bureau of Soils. There were slight changes in texture.

 34 inches—A stiff clay horizon.

 Inspection of a deep cut on the roadside near the location of the sample station showed that at 6 feet and deeper there existed a heavy reddish clay. In the immediate locality the road sections showed that the parent rock was deeper than the 6 foot section. The slope of the land at the sample station was quite steep.

History: Tom Burns, Irvington, owner. Field has been in pasture for the past 3 years at least, and probably for a much longer time. Sample collected September 2, 1915.

Depths of horizons:
 7–A 0–12 inches. 7-B 12–24 inches. 7–C 24–36 inches.

No. 10—*San Joaquin Sandy Loam*

Location: North Sacramento, Sacramento County; ¼ mile east of tile factory, across the road; opposite poles 57/32 and 57/33, 75 feet southeast from the State Highway.

Soil: 0 26 inches—A brownish red sandy loam, slightly hog wallowed, and very slightly rolling.

 26 36 inches—A sandy clay loam.

 36 inches—A *hard* hardpan.

History: Owner not known, the district now being subdivided, the property being a portion of the old "Hagan Grant." A near-by resident gave the following information: "The land has not been cultivated for the past 15 years or more. The land is said to have been farmed to grain at one time for a few years, but the 'soil is too light for wheat, it grows nothing but filaree.' " The principal use has been for cattle and sheep pasture. Sample collected March 28, 1916.

Depths of horizons:
 10-A 0–12 inches. 10–B 12–24 inches. 10–C 24–36 inches.

No. 11—*San Joaquin Sandy Loam*

Location: Four miles west of Lincoln, Placer County, at the "Road Corners," in the southeast field, 10 feet east of the west fence and 60 feet south of the north fence.

Soil: A gently hog wallowed, sandy loam, with some deeper depressions, prob-
ably stream channels. Sample slightly gravelly.

    0–12 inches—Brownish or *reddish* brown sandy loam.

    12–17 inches —Sandy clay loam or clay, color the same.

    17–23 inches—A stiff reddish *brown* clay.

    23 inches—A *hard* hardpan.

History: Mr. Frank Dowd, owner. The land has been planted to wheat for the
past 20 or 25 years; previous to that time it was used for pasture. Six
to 10 or 12 bushels of wheat, and 8 to 20 bushels of barley is the production
of this soil in the locality. The soil is usually fallowed on alternate years.
Land held at from $30 to $50 per acre. Sample collected March 28, 1916.

Depths of horizons:

    11–A   0–11 inches.   11–B   11–17 inches.   11–C   17–23 inches.

No. 12—San Joaquin Sandy Loam

Location: About 6 miles west of Wheatland, Sutter County. Near a road corner,
in a little swale west of a knoll, 15 feet east of the westerly fence of field,
and 150 feet south of the north line of the westerly road.

Soil: Texture slightly heavy, and barely enough sand for a sandy loam, but the
best found for several miles. Color brownish red, the same throughout the
entire depth.

    0 18 inches—Light, fine textured, sandy loam.

    18 -31 inches—Heavy sandy clay loam, running into a stiff clay.

    31 inches—Hardpan, sandy and somewhat soft. The ground was very
moist at this time.

History: Very evidently pasture for sheep and cattle. No signs of having been
cultivated for several years, at least. The cover is of a number of low
annuals—*Orthocarpus, Trifolium, Centaurea,* and others. Sample collected
March 29, 1916.

Depths of horizons:

    12–A   0–12 inches.   12–B   12–18 inches.   12–C   18–31 inches.

No. 13—San Joaquin Sandy Loam

Location: Three and three-quarters miles east of Elk Grove, Sacramento County.
On the Sheldon road, about 30 feet northwest from the fence on the north
side of the road. About 200 feet southwest from where a house formerly
stood.

Soil: A reddish *brown* sandy loam, approaching a loam; becoming redder in
color with increasing depth.

    0–14 inches—Heavy sandy loam.

    14- 22 inches—Clay loam.

    22- 29 inches—Heavy clay loam.

    29 inches—Compact hardpan.

History: Wackman Brothers, Elk Grove, owners. The land has not been plowed
or farmed for at least 15 years. The land is held at about $50 per acre.
Sample collected March 30, 1916.

Depths of horizons:

    13–A   0–12 inches.   13–B   12–22 inches.   13–C   22–29 inches.

No. 14—Hanford Fine Sandy Loam

Location: One mile southeast of the Sheldon road, 3½ miles east of Elk Grove, Sacramento County. On the southwest side of the secondary road, in alfalfa field, about 25 feet from the fence. Station on a little rise.

Soil: 0–11 inches—A medium brown micaceous heavy fine sandy loam.
   11–24 inches—A dark gray to black fine sandy loam, grading into the following.
   24–36 inches—Brown fine sandy loam. Water table at 32 inches.

History: Mrs. A. C. Freeman, Elk Grove, owner. Land planted to alfalfa. Good growth. No irrigation. Willows as well as alders and river ash along the sloughs. Many scattering valley oaks. The land is subject to overflow from the Cosumnes River, as it lies low in the river bottom, and shallow stream channels and sloughs are frequent. Sample collected March 30, 1916.

Depths of horizons:
   14–A   0–12 inches.   14–B   12–24 inches.   14–C   24–36 inches.

No. 15—Hanford Fine Sandy Loam

Location: North of Woodbridge, San Joaquin County, along the State Highway, less than ¼ mile south of the road running westerly from Acampo to the highway. Station in a vineyard, with almond trees along the roadside, 20 feet northeast of "change telephone pole," 200 feet north of pine tree at the gateway on the opposite side of the highway. (For map, see under sample 16.)

Soil: Texture a rather coarse fine sandy loam; it was hard to find a good fine sandy loam. Color when moist was a medium brown throughout the 3 foot section; the field color was a light grayish brown.

History: Mike Nolan estate, owner. The vineyard is of Tokay grapes, 10 to 12 years old. The land is held at $300 to $400 per acre. It is said to be a losing game to farm this land to grapes at this valuation. Sample collected March 30, 1916.

Depths of horizons:
   15–A   0–12 inches.   15–B   12–24 inches.   15–C   24–36 inches.

No. 16—Hanford Fine Sandy Loam

Location: Along the road north of Woodbridge, San Joaquin County. In a young pear orchard about 65 feet west of the highway, and about 95 feet north of the north abutments of the bridge over Mokelumne River.

Soil: A medium brown fine sandy loam, similar throughout the soil column of three feet. This soil is of the recent, flood-plain phase of the type, though this station is not known to have been under water for a number of years, at least. There is only a comparatively narrow shelf of this phase between the older, higher phase, and the river.

History: A. Perrin, Woodbridge, owner. The land had always been in brush and pasture until it was cleared and planted to pears in 1911. Value about $500 per acre. Sample collected March 30, 1916.

Depths of horizons:
   16–A   0–12 inches.   16–B   12–24 inches.   16–C   24–36 inches.

No. 17—San Joaquin Sandy Loam

Location: A short distance south of the east and west road that runs east to Thalheim, San Joaquin County. The station was on a slight knoll 75 feet south of a canal, and the same distance east of the secondary road running north and south; not far from a vacant barn.

Soil: 0–12 inches—Reddish brown.

12–24 inches—Slightly redder.

24 inches—Hardpan.

The surface had the characteristic hog wallows, and the usual scant vegetation of grasses and herbs, ''filaree'' being abundant; yet all vegetation was more abundant than that in pastured fields.

History: Rev. Frank Hoffman, Acampo, owner. Apparently, the land has not been cultivated in recent years. Sample collected March 31, 1915.

Depths of horizons:

17–A   0–12 inches.   17–B   12–24 inches.

No. 18—San Joaquin Sandy Loam

Location: Two and one-half miles northwest of Madera, Madera County. Along State Highway, 75 to 100 feet southwest of the paved road, at telephone pole 92/29; across the highway from the driveway to the house.

Soil: 0–5 inches—A light reddish brown sandy loam. A noticeable plow pan at 5 inches.

5–24 inches—A light brownish red sandy loam, becoming heavier below.

24–30 inches—Quite compact heavy sandy loam.

30 inches and deeper—A *very compact* hardpan.

Topography very gently rolling, hog wallows well developed, though considerably degraded by cultivation. Barley grain not growing well in the lower spots.

History: Cropped for probably 20 years to grains; barley at present. Land used for pasture previous to grain farming. A good yield is 8 sacks, varying from that down to little or nothing. Miller and Lux, owners. Sample collected April 11, 1916.

Depths of horizons:

18–A   0–12 inches.   18–B   12–24 inches.   18–C   24 30 inches.

No. 19—Hanford Fine Sandy Loam

Location: Eight miles east of Waterford, Stanislaus County, near Robert's Ferry bridge. About 75 feet west of the road that runs south from the bridge onto the bluff. About 450 feet north of the driveway to the Sawyer place. Twenty-five feet inside of the fence, in the alfalfa field.

Soil: Medium brown fine sandy loam; a good brown color when moist. Texture somewhat variable, some rounded gravels up to the size of a hen's egg. Topography undulating, and more or less terraced, due to the old stream channels.

History: G. H. Sawyer, Waterford, owner. Alfalfa planted in 1915, looks well. Land previously planted to barley and wheat, with a production about as follows: barley, 14 sacks is considered good; wheat with 12 sacks is good, with 6 sacks a low average. Value of the land as recently determined in court, in a case of flood damage by a canal break, is $100 per acre. On an adjoining piece of land young walnut trees are doing very well. Sample collected April 11, 1916.

Depths of horizons:

19–A   0–12 inches.   19–B   12–24 inches.   19–C   24–36 inches.

No. 20—Hanford Fine Sandy Loam

Location: Near Hopeton, Merced County, 14 miles north of Merced. Less than ¼ mile north from the road corners, 15 feet east of the east fence of the road, and 150 feet south of irrigating ditch.

Soil: A good medium brown fine sandy loam. The color is especially good when the soil is moist. The topography is slightly uneven because of the old stream channels. Going north along the road from the cross roads the soil is quite gravelly at first, but the texture gradually becomes heavier, with less gravel. At the sample station the texture is a rather heavy fine sandy loam.

History: J. G. Ruddle, Snelling, owner. The field is planted to alfalfa, as are most of the Hanford soils in the locality. The land is not subject to overflow. Sample collected April 13, 1916.

Depths of horizons:
   20–A   0–12 inches.   20–B   12–24 inches.   20–C   24–36 inches.

No. 21—San Joaquin Sandy Loam

Location: Near Nairn Station, Merced County. About ¼ mile west of the railroad, 50 feet north of the private ranch road, and 120 feet east of the field gate across the road. About 4 miles northwest of Merced.

Soil: A good brownish red San Joaquin color. Texture a sandy loam, grading into a clay loam or clay at about 24 inches.

Depths of horizons:
   24–27 inches—A heavy clay.
   27 inches—Hardpan.
   The same was taken from near the top of one of the hog wallow elevations. The topography is gently rolling.

History: F. W. Henderson, Merced, owner. At the present time the land is used as pasture. It has been plowed at some time in the past. The present growth of wild herbage (*Lepidium*, small grasses, *Cryptanthe*, etc.) is meager. Sample collected April 13, 1916.

Depths of horizons:
   21–A   0–12 inches.   21–B   12–24 inches.   21–C   24–27 inches.

No. 22—Hanford Fine Sandy Loam

Location: A short distance north of Basset, Los Angeles County, on the main road north from Basset station. The sample was collected in a walnut grove 100 feet east of the road and 250 feet south of the driveway to the ranch house.

Soil: A good medium brown when moist, and a light grayish brown when dry. Mr. L. C. Holmes, of the U. S. Bureau of Soils, described the soil at the time of collection as being "all a little browner, and with a little more color than a good Hanford." There was a very slight color change at about a foot, the soil below was grayer. Texture a good fine sandy loam, with practically no change in the 3 foot column. Topography smooth. The texture varies quite rapidly from place to place in the field. Some big washes of typical intermittent streams are found not far to the north and west.

History: C. N. Basset, of Basset and Nebeker, Santa Monica, owner. The land is planted to walnuts, and the trees are about 10 years old. They are doing well, some replants are found. The trees are irrigated. Sample collected May 22, 1916.

Depths of horizons:

22–A   0–12 inches.   22–B   12–24 inches.   22–C   24–36 inches.

No. 23—Hanford Fine Sandy Loam

Location: South and west of the town of Anaheim, Orange County. Within a radius of 20 feet of where the official Bureau of Soils sample was taken. Thirty feet east of side road, and 100 feet north of main east and west road.

Soil: Brown fine sandy loam, possibly a little more silty than no. 22, but not heavy enough for a heavy fine sandy loam. Dry field color a light, grayish brown. Topography smooth, no stream channels visible. Irrigation in furrows. Soil similar to about 62 inches, a *little* more grayish at 18 inches, the change being gradual. At 62 inches a gray clean sand, or fine sand, was found.

History: S. J. Luhring, R. F. D. no. 4, owner. The field was planted to Valencia oranges in 1913; previously to grapes and miscellaneous crops. Sample collected May 23, 1916.

Depths of horizons:

23–A   0–12 inches.   23–B   12–24 inches.   23–C   24–36 inches.

No. 24—Hanford Fine Sandy Loam

Location: Southeast of the center of Los Angeles, half way from Magnolia Avenue on Fruitland Road, to Salt Lake Railroad on the east. South side of the road about 60 feet from center, in edge of corn field. Just across road from east end of east cypress trees.

Soil: A medium brown fine sandy loam when moist; color in the field is a *grayish* brown. Micaceous. Topography level, no stream channels seen nearby. Color of body variable. Sample location in the browner phase. Toward south and east along the railroad and Arcadia Avenue the color is much grayer, and even black when moist. Texture within the body is very variable, though always within the fine sandy loam group.

0–36 inches—Fine sandy loam, grayer below.

36–37 inches—Layer of grayish sand and fine sand.

37–72 inches—Fine sandy loam, heavier in streaks.

History: C. D. Templeman, R. F. D. no. 2, Box 178, Los Angeles, owner. Land has been in truck for 10 or 12 years. Only fertilizer, barnyard manure. Sample collected May 24, 1916.

Depths of horizons:

24–A   0–12 inches.   24–B   12–24 inches.   24–C   24–36 inches.

No. 25—Hanford Fine Sandy Loam

Location: Near Van Nuys, Los Angeles County; near official sample station. Seventy-five feet west of center of road, between fourth and fifth rows of apricot trees north from boundary.

Soil: A good medium brown fine sandy loam; the field color a grayish brown. The texture uniform throughout the 3 foot section, with a little gravel occasionally. Also the texture is variable to about the usual degree, in the field distribution. The color is slightly lighter at about 2 feet and below throughout the 6 feet, with a little variation in an increasing amount of coarser sands. ·

History: Chase, Riverside, owner (?). Planted to apricots, 2 years old. Interplanted to melons. Sample collected May 24, 1916.

Depths of horizons:
25–A   0–12 inches.   25–B   12–24 inches.   25–C   24–36 inches.·

No. 26—San Joaquin Sandy Loam

Location: On the high bluffs about 1¼ miles southeast of Del Mar station, San Diego County, close to the road that runs back along the main ridge. About 50 feet north of the road where it swings south to get around the head of the big arroyo from the north.

Soil: A brownish red sandy loam. Surface covered with a moderate growth of the low chapparal common to these exposed ridges. Soil heavily laden with iron concretions. Surface has the usual hog wallows characteristic of the San Joaquin series.

0– 6 inches—Reddish brown sandy loam, many concretions. Dry.

6–13 inches—Clay (sandy), reddish in cracks, and bluish inside of lumps and where not weathered.

13–22 inches—Clay, mostly bluish gray.

22–38 inches—Boring very difficult, due to the heavy nature of the clayey moist material. Color bluish.

About 40 inches—Hardpan. Very compact.   ●

History: Probably never farmed. Recently streets cleared, and an attempt made to sell lots for building. Value for agriculture—none without irrigation. Sample collected May 25, 1916.

Depths of horizons:
26–A   0–6 inches.   26–B   6–13 inches.   26–C   13–22 inches.
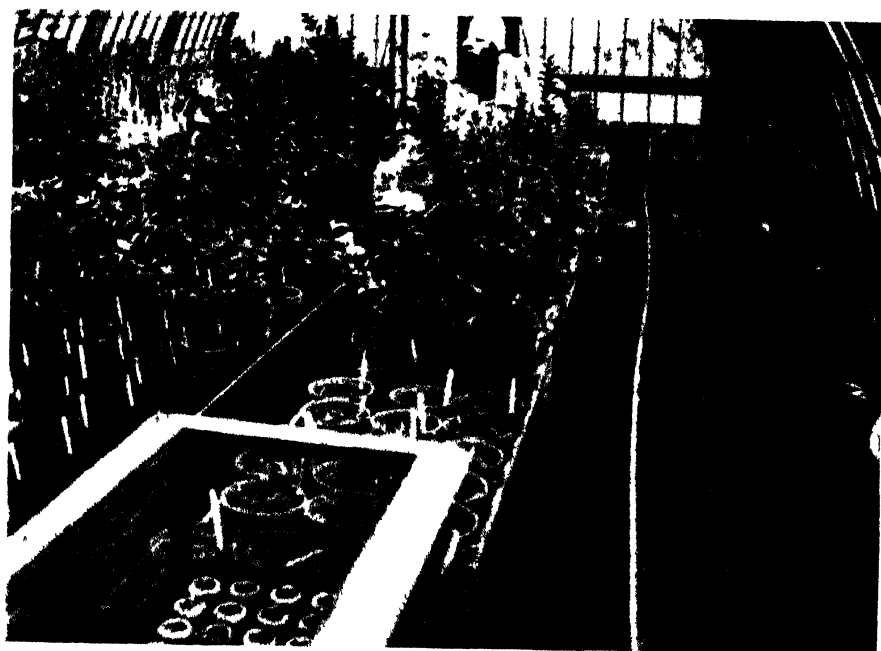
A general view in the greenhouse, where all the pot culture work was carried on The entire right hand bench was devoted to this study, also half again as much space not visible in the print.

DIABLO CLAY ADOBE—FIRST CROP

Pots of same and different representatives of a given soil type compared

Fig 1 Oats and bur clover Left to right—Soil 1, pot 1, soil 2, pot 2, soil 5, pot 1, soil 6, pot 3

DIABLO CLAY ADOBE—FIRST CROP

Pots of same and different representatives of a given soil type compared

Fig 2 Oats Left to right –Soil 1, pot 1, soil 2, pot 3, soil 5, pot 2, soil 6, pot 2.

DIABLO CLAY ADOBE— FIRST CROP

Pots of same and different representatives of a given soil type compared

Fig 1   Bur clover   Left to right   Soil 1 pot 1   soil 1 pot 2   soil 1 pot 3

DIABLO CLAY ADOBE —FIRST CROP

Pots of same and different representatives of a given soil type compared

Fig 2   Bur clover   Left to right—Soil 2 pot 1   soil 2 pot 2   soil 2 pot 3

DIABLO CLAY ADOBE—FIRST CROP

Pots of same and different representatives of a given soil type compared

Fig 1 Bur clover Left to right Soil 5 pot 1 soil 5, pot 2, soil 5 pot 3

DIABLO CLAY ADOBE—FIRST CROP

Pots of same and different representatives of a given soil type compared

Fig 2 Bur clover Left to right—Soil 6, pot 1, soil 6, pot 2, soil 6, pot 3

DIABLO CLAY ADOBE — FIRST CROP

Lots of same and different representatives of a given soil type compared

Pur clover — Left to right — Soil 1, pot 1 — soil 2, pot 2 — soil 5, pot 2 — soil 6, pot 1
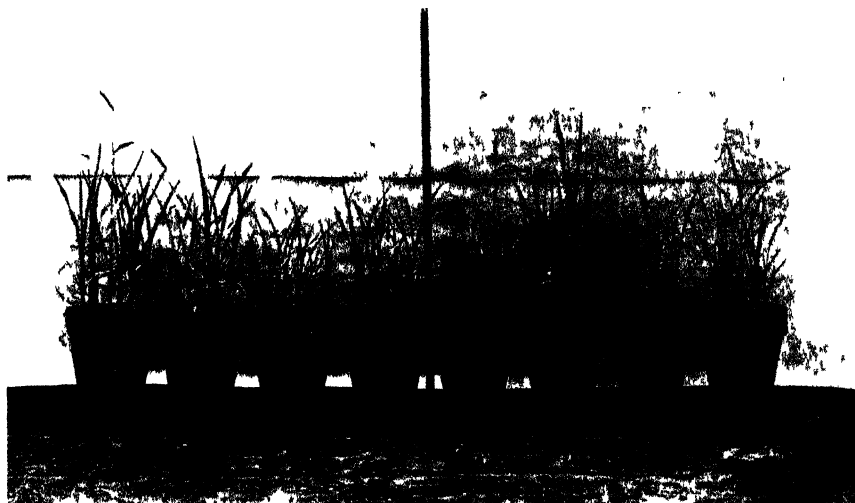
DIABLO CLAY ADOBE—SECOND CROP

Pots of same and different representatives of a given soil type compared

Fig 1   Dwarf milo (a) following oats   Left to right—Soil 1, pot 2 soil 1,
pot 5 soil 2 pot 1 soil 2, pot   soil 5 pot 1 soil 5 pot 3 soil 6, pot 2 soil 6,
pot 3

DIABLO CLAY ADOBE—SECOND CROP

Pots of same and different representatives of a given soil type compared

Fig 2   Dwarf milo (b) following oats and bur clover   Left to right —Soil 1,
pot 1 soil 1, pot 3 soil 2, pot 1 soil 2 pot 3 soil 5, pot 1 soil 5, pot 5 soil 6,
pot 1, soil 6, pot 3

DIABLO CLAY ADOBE—SECOND CROP

Pots of same and different representatives of a given soil type compared

Fig 1   Cowpeas following wheat   Left to right—Soil 1 pot 1 soil 1, pot 2 soil 2 pot 1 soil 2, pot 2 soil 5, pot 1 soil 5 pot 2 soil 6, pot 2 soil 6 pot 5

DIABLO CLAY ADOBE—SECOND CROP

Pots of same and different representatives of a given soil type compared

Fig 2   Soy beans, following barley   Left to right- Soil 1 pot 1 soil 1, pot 2, soil 2, pot 1, soil 2, pot 3, soil 5, pot 1, soil 5, pot 2, soil 6, pot 1, soil 6, pot 2

ALTAMONT CLAY LOAM—SECOND CROP

Pots of same and different representatives of a given soil type compared

Cowpeas B following barley. Left to right: Soil 5 pot 1, soil 3 pot—
soil 4 pot 1, soil 4, pot 5, soil 7 pot 1, soil 7, pot 5.

ALTAMONT CLAY LOAM—SECOND CROP

Pots of same and different representatives of a given soil type compared.

Fig. 1. Soy beans A, following oats. Left to right—Soil 3, pot 1; soil 3, pot 2; soil 4, pot 2; soil 4, pot 3: soil 7, pot 2: soil 7, pot 3.

ALTAMONT CLAY LOAM—SECOND CROP

Pots of same and different representatives of a given soil type compared.

Fig. 2. Soy beans B, following *Phaseolus*. Left to right—Soil 3, pot 2; soil 3, pot 3; soil 4, pot 1; soil 4, pot 2; soil 7, pot 1; soil 7, pot 2.

ALTAMONT CLAY LOAM—SECOND CROP

Pots of same and different representatives of a given soil type compared

Fig 1   Dwarf milo A, following wheat   Left to right—Soil 3, pot 2, soil 3, pot 3 soil 4, pot 1, soil 4, pot 3, soil 7, pot 1 soil 7, pot 3

ALTAMONT CLAY LOAM—SECOND CROP

Pots of same and different representatives of a given soil type compared

Fig 2   Dwarf milo A following bur clover   Left to right—Soil 3, pot 1, soil 3, pot 2, soil 4, pot 1, soil 4, pot 3, soil 7, pot 1, soil 7, pot 3

HANFORD FINE SANDY LOAM – FIRST CROP

Pots of same and different representatives of a given soil type compared

Fig 1   Dwarf milo A   Left to right – Soil 14, pot 2   soil 15, pot 2   soil 16, pot 3   soil 19   pot 3   soil 20   pot 2   soil 22   pot 2, soil 23   pot 1   soil 24, pot 2   soil 25, pot 1

HANFORD FINE SANDY LOAM – FIRST CROP

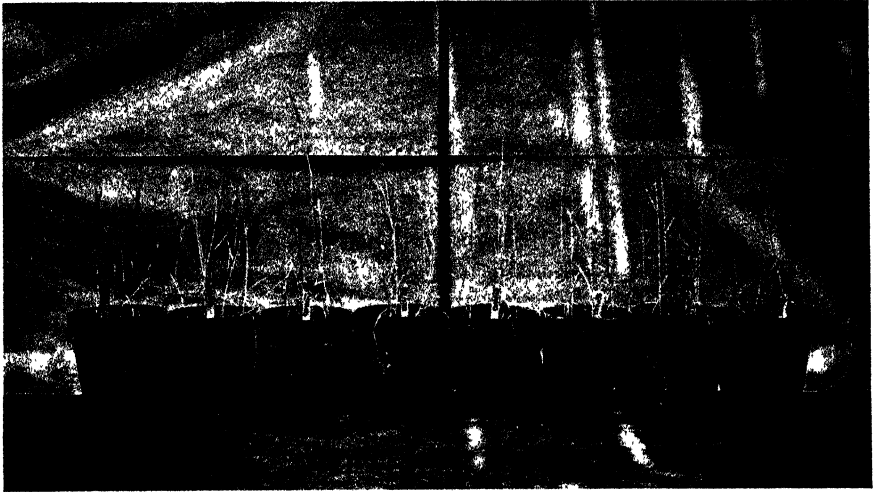Pots of same and different representatives of a given soil type compared

Fig 2   Dwarf milo A   Left to right – Soil 15, pot 1, soil 15, pot 2, soil 15, pot 3, soil 20, pot 1, soil 20, pot 2, soil 20, pot 3, soil 23, pot 1, soil 23, pot 2 soil 23, pot 3
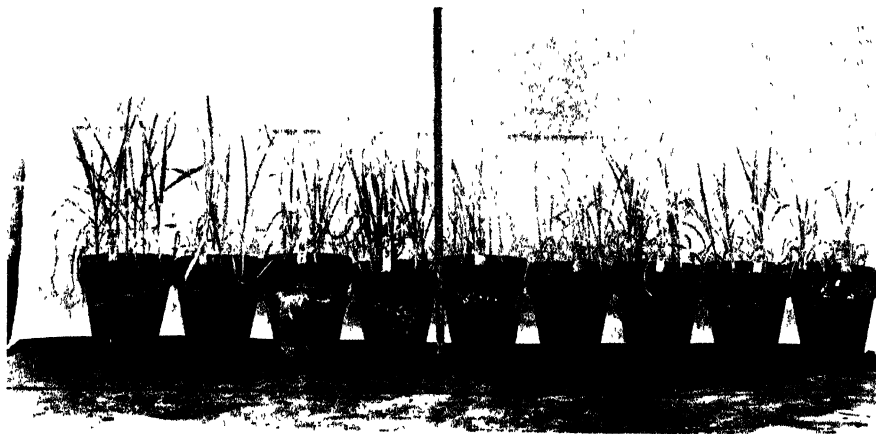
HANFORD FINE SANDY LOAM—FIRST CROP

Pots of same and different representatives of a given soil type compared.

Fig. 1. Dwarf milo B. Left to right--Soil 14, pot 3; soil 15, pot 2; soil 16, pot 1, so 1 19, pot 3; soil 20, pot 2; soil 22, pot 3, soil 23, pot 3; soil 24, pot 2; soil 25, pot 3.

HANFORD FINE SANDY LOAM—FIRST CROP

Pots of same and different representatives of a given soil type compared.

Fig. 2. Dwarf milo B. Left to right—Soil 14, pot 1; soil 14, pot 2; soil 14, pot 3; soil 22, pot 1; soil 22, pot 2; soil 22, pot 3; soil 23, pot 1; soil 23, pot 2, soil 23, pot 3.
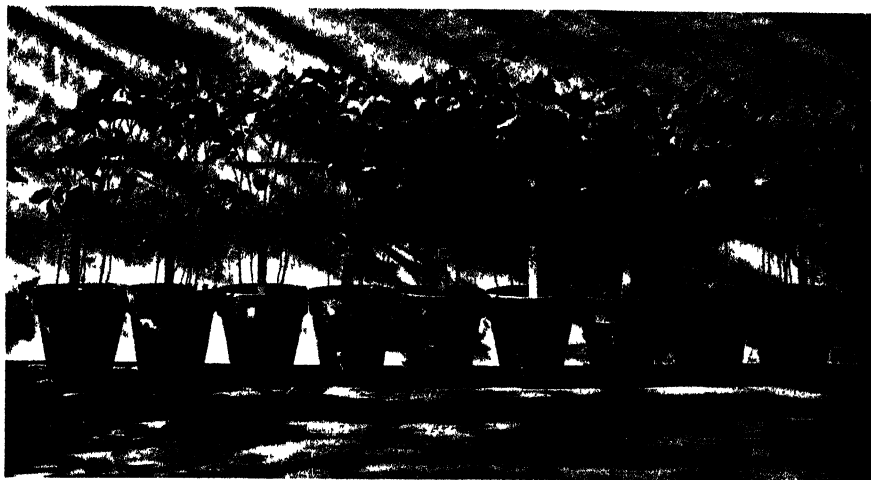
HANFORD FINE SANDY LOAM—FIRST CROP

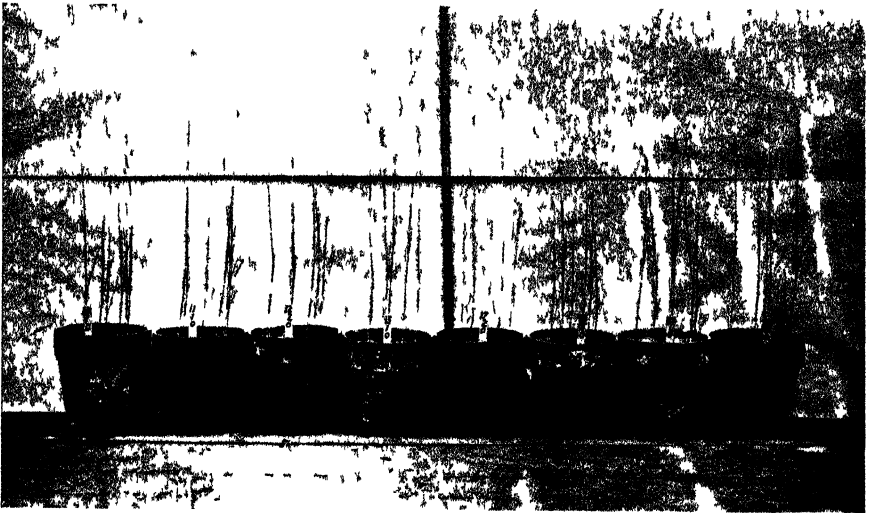Pots of same and different representatives of a given soil type compared.

Fig. 1. Soy beans. Left to right—Soil 14, pot 1, soil 15, pot 1; soil 16, pot 2; soil 19, pot 2; soil 20, pot 3; soil 22, pot 1; soil 23, pot 3; soil 24, pot 1; soil 25, pot 3.
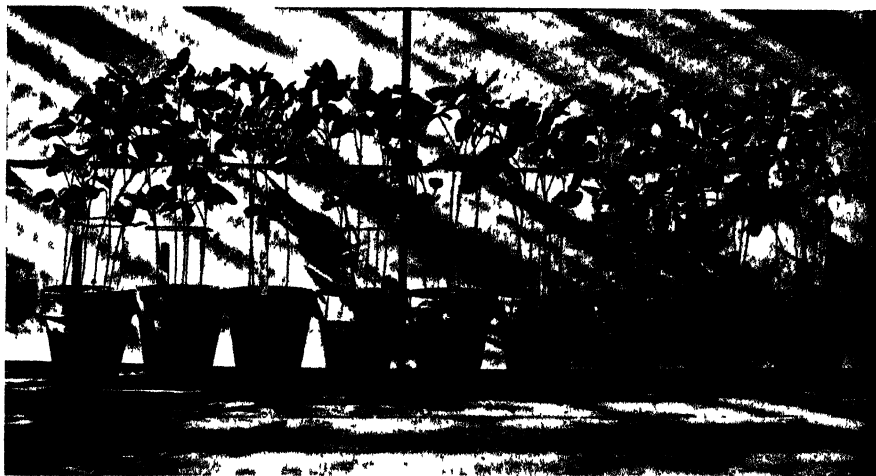
HANFORD FINE SANDY LOAM—FIRST CROP

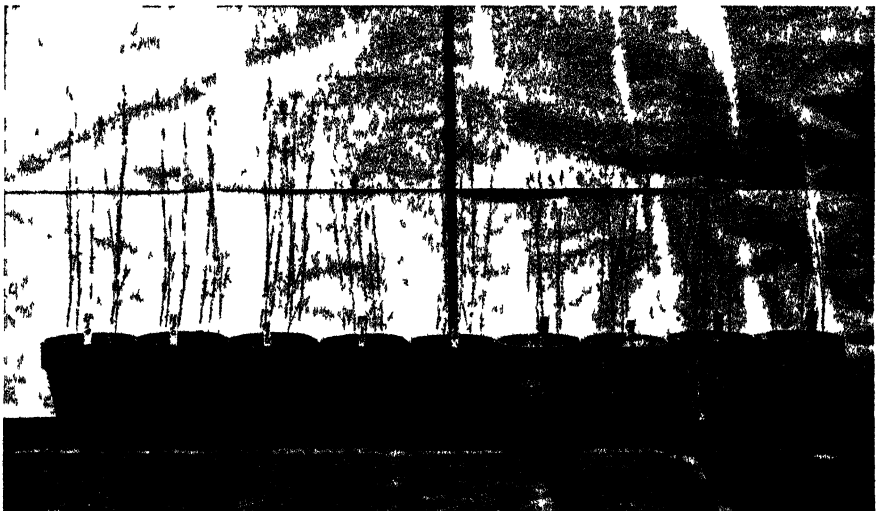Pots of same and different representatives of a given soil type compared.

Fig. 2. Soy beans. Left to right—Soil 14, pot 1; soil 14, pot 2; soil 14, pot 3; soil 16, pot 1; soil 16, pot 2; soil 16, pot 3; soil 23, pot 1; soil 23, pot 2; soil 23, pot 3.

HANFORD FINE SANDY LOAM—FIRST CROP

Pots of same and different representatives of a given soil type compared.

Fig. 1. Cowpeas B. Left to right—Soil 14, pot 1; soil 14, pot 2; soil 14, pot 3; soil 22, pot 1; soil 22, pot 2; soil 22, pot 3; soil 23, pot 1; soil 23, pot 2; soil 23, pot 3.
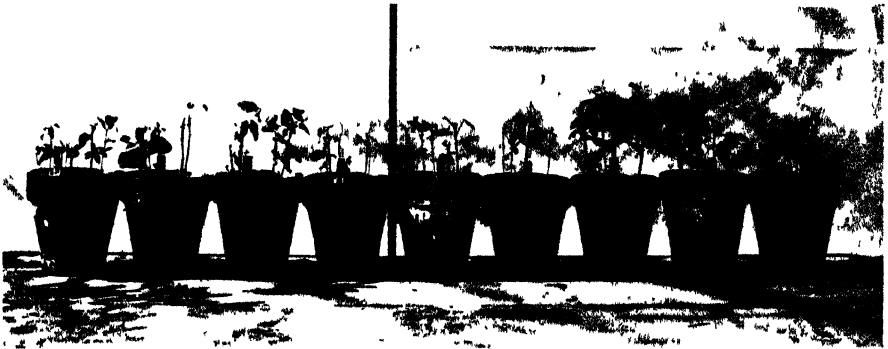
HANFORD FINE SANDY LOAM—FIRST CROP

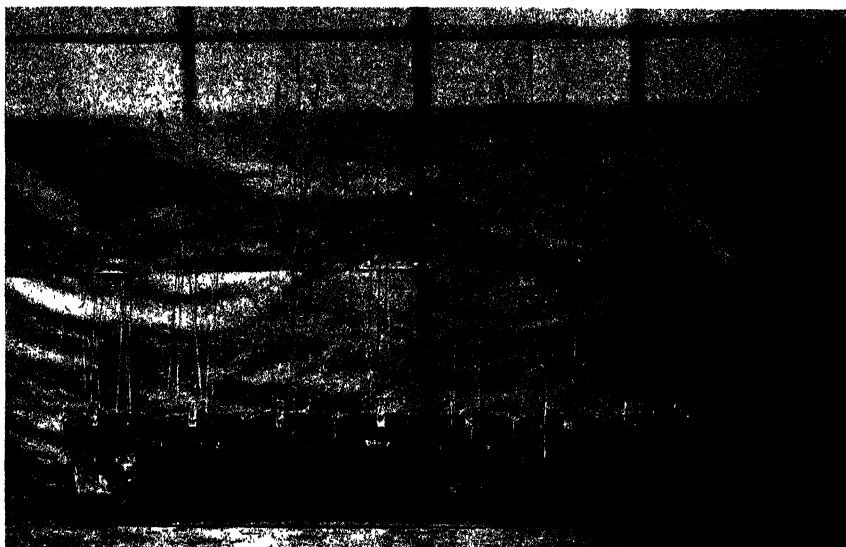Pots of same and different representatives of a given soil type compared.

Fig. 2. Cowpeas B. Left to right—Soil 14, pot 3; soil 15, pot 2; soil 16, pot 2; soil 19, pot 2; soil 20, pot 2; soil 22, pot 2; soil 23, pot 2; soil 24, pot 1; soil 25, pot 3.
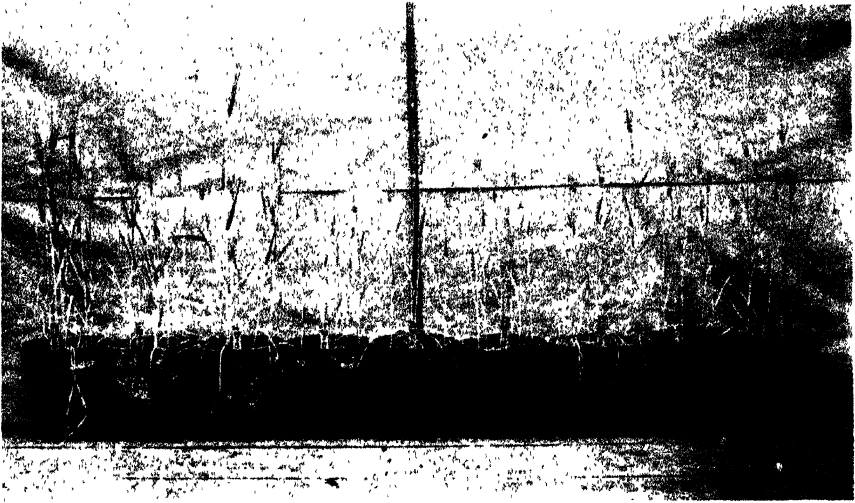
HANFORD FINE SANDY LOAM—SECOND CROP

Pots of same and different representatives of a given soil type compared.

Fig. 1. Barley, following soy beans. Left to right—Soil 14, pot 2; soil 15, pot 1; soil 16, pot 3; soil 19, pot 3; soil 20, pot 1; soil 22, pot 2; soil 23, pot 3; soil 24, pot 3; soil 25, pot 1.

HANFORD FINE SANDY LOAM—SECOND CROP

Pots of same and different representatives of a given soil type compared.

Fig. 2. Barley, following soy beans. Left to right—Soil 14, pot 1; soil 14, pot 2; soil 14, pot 3; soil 19, pot 1; soil 19, pot 2; soil 19, pot 2; soil 19, pot 3; soil 23, pot 1; soil 23, pot 2; soil 23, pot 3.
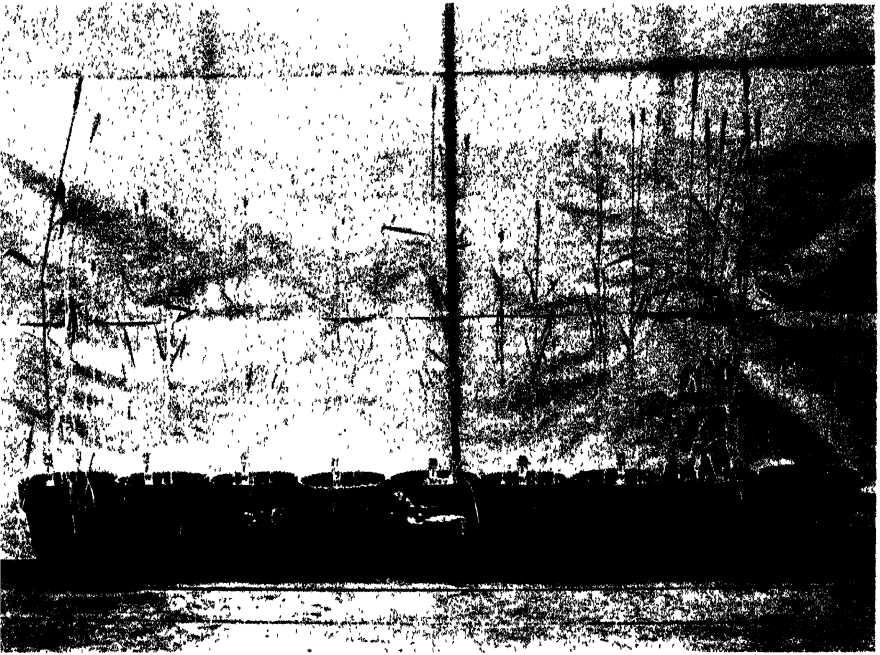
HANFORD FINE SANDY LOAM—SECOND CROP

Pots of same and different representatives of a given soil type compared.

Wheat, following millet. Left to right—Soil 14, pot 1; soil 15, pot 1; soil 16, pot 1; soil 19, pot 3; soil 20, pot 1; soil 22, pot 1; soil 23, pot 1; soil 24, pot 1; soil 25, pot 3.

HANFORD FINE SANDY LOAM—SECOND CROP

Pots of same and different representatives of a given soil type compared.

Wheat, following millet. Left to right—Soil 16, pot 1, soil 16, pot 2, soil 16, pot 3, soil 22, pot 1; soil 22, pot 2, soil 22, pot 3, soil 24, pot 1, soil 24, pot 2, soil 24, pot 3.

HANFORD FINE SANDY LOAM—SECOND CROP

Pots of same and different representatives of a given soil type compared

Fig 1 Barley, following cowpeas Left to right—Soil 14, pot 2, soil 15, pot 3, soil 16, pot 2, soil 19, pot 2, soil 20, pot 1, soil 22, pot 3, soil 23, pot 3, soil 24, pot 3, soil 25, pot 1.

HANFORD FINE SANDY LOAM—SECOND CROP

Pots of same and different representatives of a given soil type compared

Fig. 2 Barley, following cowpeas Left to right—Soil 19, pot 1, soil 19, pot 2, soil 19, pot 3, soil 20, pot 1, soil 20, pot 2, soil 20, pot 3, soil 23, pot 1; soil 23, pot 2, soil 23, pot 3.

HANFORD FINE SANDY LOAM—SECOND CROP

Pots of same and different representatives of a given soil type compared

Fig 1   Oats, following milo   Left to right—Soil 14, pot 3   soil 15, pot 2   soil 16, pot 2   soil 19, pot 1   soil 20   pot 2   soil 22, pot 1   soil 23, pot 3, soil 24, pot 1   soil 25, pot 1
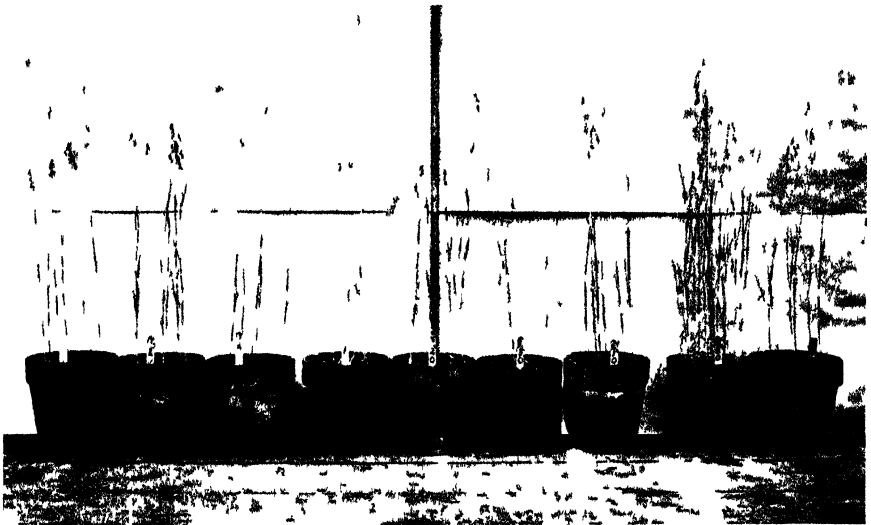
HANFORD FINE SANDY LOAM—SECOND CROP

Pots of same and different representatives of a given soil type compared

Fig 2   Oats, following milo   Left to right—Soil 14, pot 1, soil 14, pot 2, soil 14, pot 3, soil 15, pot 1, soil 15, pot 2, soil 15, pot 3, soil 24, pot 1, soil 24, pot 2, soil 24, pot 3

HANFORD FINE SANDY LOAM—SECOND CROP

Pots of same and different representatives of a given soil type compared

Melilotus indica following cowpeas Left to right—Soil 14, Pot 1 Soil 15, Pot 3 Soil 16 Pot 2 Soil 19 Pot 2 Soil 20 Pot 1

HANFORD FINE SANDY LOAM—SECOND CROP

Pots of same and different representatives of a given soil type compared
Melilotus indica following cowpeas Left to right—Soil 22, Pot 2 Soil 23,
Pot 1 Soil 24 Pot 1 Soil 25 Pot 1

HANFORD FINE SANDY LOAM—SECOND CROP

Pots of same and different representatives of a given soil type compared.

Melilotus indica, following cowpeas. Left to right—Soil 15, Pot 1; Soil 15, Pot 2, Soil 15, Pot 3; Soil 23, Pot 1.

HANFORD FINE SANDY LOAM—SECOND CROP

Pots of same and different representatives of a given soil type compared.

Melilotus indica, following cowpeas. Left to right—Soil 23, Pot 2, Soil 23, Pot 3, Soil 25, Pot 1, Soil 25, Pot 2, Soil 25, Pot 3

HANFORD FINE SANDY LOAM—SECOND CROP

Pots of same and different representatives of a given soil type compared.

Bur clover, following milo. Left to right—Soil 14, Pot 1; Soil 15, Pot 1; Soil 16, Pot 2; Soil 19, Pot 1; Soil 20, Pot 1.

HANFORD FINE SANDY LOAM—SECOND CROP

Pots of same and different representatives of a given soil type compared.

Bur clover following milo. Left to right—Soil 22, Pot 1; Soil 23, Pot 1; Soil 24, Pot 1; Soil 25, Pot 1.

HANFORD FINE SANDY LOAM—SECOND CROP

Pots of same and different representatives of a given soil type compared.

Bur clover, following milo. Left to right—Soil 19, Pot 1; Soil 19, Pot 2; Soil 19, Pot 3; Soil 23, Pot 1; Soil 23, Pot 2.

HANFORD FINE SANDY LOAM—SECOND CROP

Pots of same and different representatives of a given soil type compared.

Bur clover, following milo. Left to right—Soil 23, Pot 3; Soil 25, Pot 1; Soil 23, Pot 2; Soil 23, Pot 3.
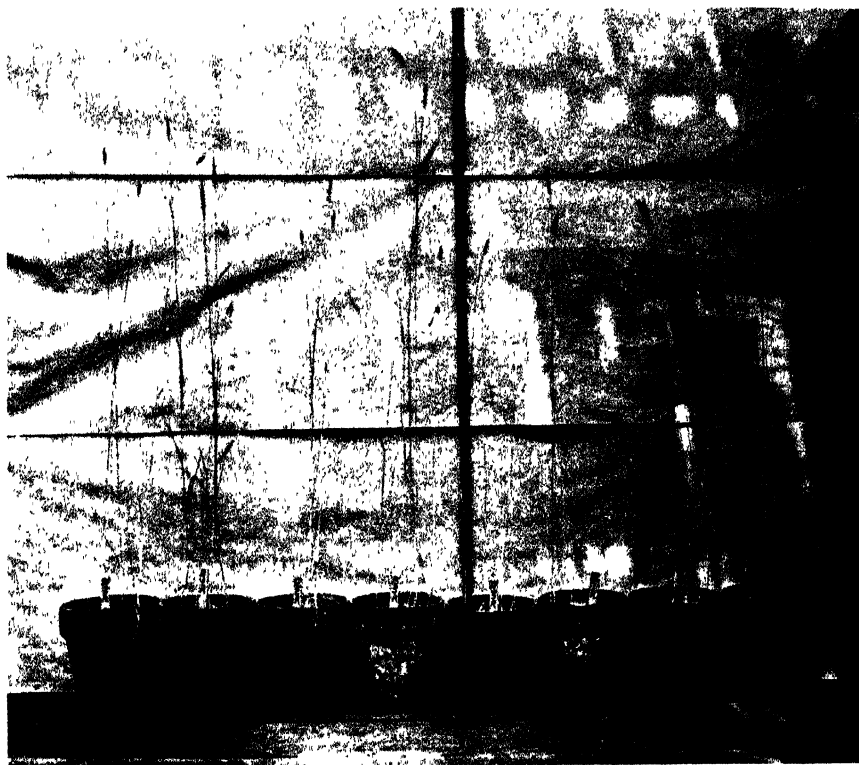
SAN JOAQUIN SANDY LOAM

Pots of same and different representatives of a given soil type compared.

Rye. Left to right—Soil 10, pot 2; soil 11, pot 1; soil 12, pot 2; soil 13, pot 3; soil 17, pot 3; soil 18, pot 1; soil 21, pot 1; soil 26, pot 1.

SAN JOAQUIN SANDY LOAM

Pots of same and different representatives of a given soil type compared

Fig 1 *Melilotus indica* Left to right—Soil 10, pot 1 soil 11, pot 3, soil 12, pot 2 soil 13 pot 1 soil 17, pot 3 soil 18, pot 3, soil 21 pot 2, soil 26, pot 1

SAN JOAQUIN SANDY LOAM

Pots of same and different representatives of a given soil type compared

Fig 2 *Melilotus indica* Left to right—Soil 13, pot 1, soil 13, pot 2, soil 13, pot 3, soil 17, pot 1, soil 17, pot 2, soil 17, pot 3, soil 26, pot 1, soil 26, pot 2, soil 26, pot 3
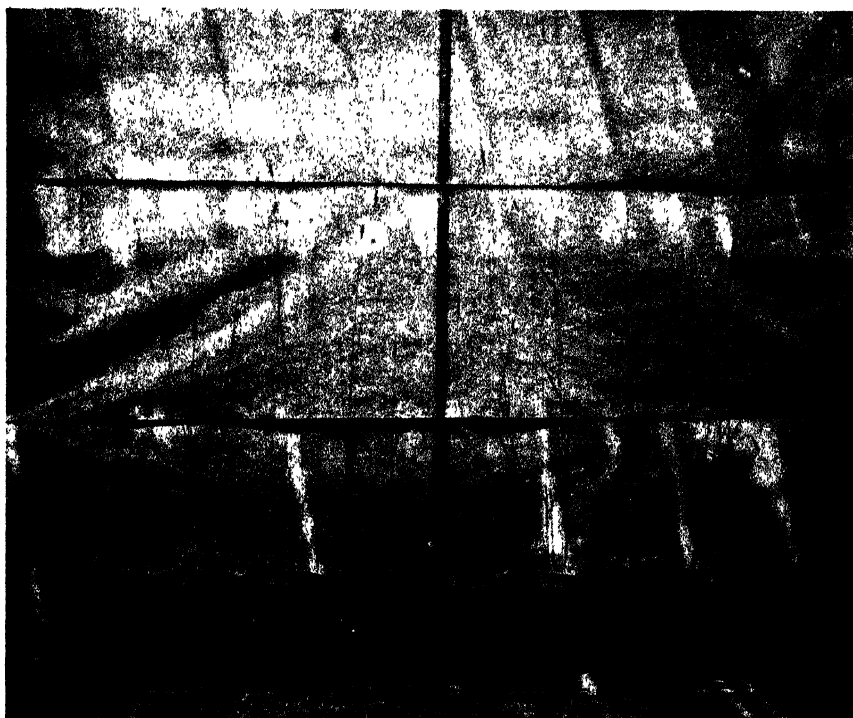
SAN JOAQUIN SANDY LOAM

Pots of same and different representatives of a given soil type compared.

Rye. Left to right—Soil 10, pot 1; soil 10, pot 2; soil 10, pot 3; soil 18, pot 1; soil 18, pot 2; soil 18, pot 3; soil 26, pot 1; soil 26, pot 2; soil 26, pot 3.

SAN JOAQUIN SANDY LOAM

Pots of same and different representatives of a given soil type compared.

Fig. 1. Barley. Left to right—Soil 10, pot 3; soil 11, pot 2; soil 12, pot 3; soil 13, pot 1; soil 17, pot 3; soil 18, pot 2; soil 21, pot 3; soil 26, pot 1.

SAN JOAQUIN SANDY LOAM

Pots of same and different representatives of a given soil type compared.

Fig. 2. Barley. Left to right—Soil 10, pot 1; soil 10, pot 2; soil 10, pot 3; soil 18, pot 1; soil 18, pot 2; soil 18, pot 3; soil 26, pot 1; soil 26, pot 2; soil 23, pot 3.

SAN JOAQUIN SANDY LOAM

Pots of same and different representatives of a given soil type compared

Fig 1   Oats   Left to right—Soil 10, pot 1, soil 11, pot 1, soil 12, pot 2, soil 13, pot 1 soil 17, pot 2 soil 18, pot 3, soil 21, pot 1, soil 2), pot 3

SAN JOAQUIN SANDY LOAM

Pots of same and different representatives of a given soil type compared

Fig 2   Oats   Left to right—Soil 11, pot 1, soil 11, pot 2, soil 11, pot 3, soil 17, pot 1, soil 17, pot 2, soil 17, pot 3, soil 21, pot 1, soil 21, pot 2, soil 21 pot 3.

SAN JOAQUIN SANDY LOAM

Pots of same and different representatives of a given soil type compared.

Fig. 1. Wheat. Left to right—Soil 10, pot 1; soil 11, pot 3; soil 12, pot 1; soil 13, pot 1; soil 17, pot 1; soil 18, pot 2; soil 21, pot 1; soil 26, pot 3.
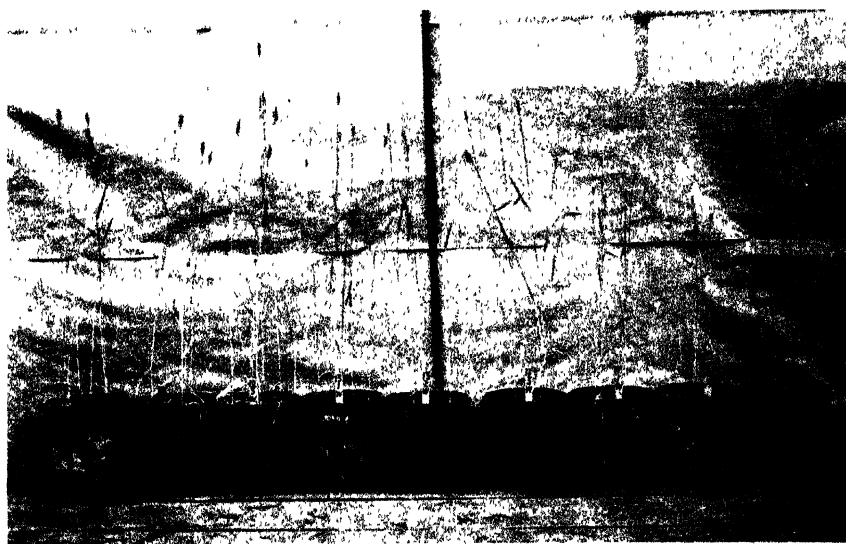
SAN JOAQUIN SANDY LOAM

Pots of same and different representatives of a given soil type compared.

Fig. 2. Wheat. Left to right—Soil 10, pot 1; soil 10, pot 2; soil 10, pot 3; soil 13, pot 1; soil 13, pot 2; soil 13, pot 3; soil 17, pot 1; soil 17, pot 2; soil 17, pot 3.

SAN JOAQUIN SANDY LOAM

Pots of same and different representatives of a given soil type compared

Fig 1 Bur clover Left to right—Soil 10, pot 2, soil 11, pot 2, soil 12, pot 3, soil 13, pot 1, soil 17, pot 3, soil 18, pot 2, soil 21, pot 1, soil 26, pot 3

SAN JOAQUIN SANDY LOAM

Pots of same and different representatives of a given soil type compared

Fig 2 Bur clover Left to right—Soil 10, pot 1, soil 10, pot 2, soil 10, pot 3, soil 18, pot 1, soil 18, pot 2, soil 18, pot 3, soil 26, pot 1, soil 26, pot 2, soil 26, pot 3